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AD A131236

HERESIES

Brief Essays on Human Factors

D. Meister

Navy Personnel Research and Development Center  
San Diego, California

March 1977

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## SUMMARY

### PROBLEM

Periodically it is desirable for a discipline to examine its underlying goals, assumptions and methodology. Such an examination may lead to a new way of looking at the discipline and hence to a new and more productive methodology.

### METHOD

Human Factors was examined in terms of the following topics:

1. The way Human Factors is defined and its differentiation from other disciplines.
2. Its relationship to the man-machine system and to system development.
3. Human Factors goals and assumptions and their implications.
4. Human Factors research needs and criteria for effective Human Factors research.
5. Human Factors successes and failures in accomplishing its goals.
6. The communication of Human Factors information.
7. The adequacy of Human Factors methodology in terms of the problems it must solve.

### RESULTS

Eighteen essays are presented in the following report. The following hypotheses are addressed in these essays:

1. There are significant differences between Human Factors and Psychology; consequently Human Factors cannot be considered a branch of Psychology.

2. Human Factors has two goals:

- a. To understand how man-machine systems function;
- b. To assist in the development of the man-machine system.

The first goal is necessary to accomplish the second and is insufficient without the second.

3. The fundamental questions which Human Factors research must answer are:

- a. What is the contribution of the personnel subsystem to the overall system output;
- b. How do personnel performance variables affect system output;
- c. How do other system elements affect personnel performance;
- d. How can one deduce from system requirements, equipment and procedural configurations their personnel implications and how to derive from personnel requirements appropriate equipment and procedural designs.

4. The subject matter of Human Factors is the man-machine system, whereas that of Psychology is the individual or group. As a result, the results of behavioral studies performed in a non-system context cannot be automatically generalized to the personnel subsystem but must be verified by further studies in the actual or simulated system. Consequently, most of the available behavioral literature cannot be accepted as descriptive of man/system performance.

5. In contrast to Psychology, purpose is central to Human Factors because the man-machine system is developed to implement a purpose stated before the system is developed. The manner in which that purpose is implemented in development (i.e., developmental processes) is an important topic of Human Factors investigation.

6. The system orientation of Human Factors requires us to deal with large scale man-machine systems as well as the single operator/console combination and

the team. Such large scale man-machine systems create problems in applying traditional experimental paradigms.

7. Traditional hypothesis-testing experimentation is less important to Human Factors than the development of performance data bases because many conclusions derived from Human Factors research can be secured phenomenologically. The development of data bases is particularly important for system development.

8. Three criteria differentiate a man-machine system from a man-machine relationship (i.e., the human use of tools and products). A man-machine system exists only when:

a. The machine exerts a reciprocal effect on the man as a function of the latter's activation of the machine. The output of the man is transformed by the machine; likewise the machine output is modified by the man. In this respect their combined output differs from either one.

b. Once activated, the machine is able to operate independently of the man.

c. The activities of both man and machine are subordinated to a common purpose.

9. There is a natural and logical relationship between Human Factors and government. Industry and universities are unlikely to provide the necessary support for Human Factors research and application.

10. In addition to internal criteria of adequate Human Factors research, e.g., experimental design, N, subject representativeness, there is an external criterion which is the extent and directness to which that research can be applied to system development. It is possible to perform valid Human Factors studies, but they may be irrelevant to the Human Factors system development goal.

11. The most important research topics (in roughly decreasing order of priority) in Human Factors involve the following needs:

a. To develop a storehouse of probabilistic data predicting the likelihood that personnel will accomplish system tasks under various conditions;

b. To determine the human performance, manning, selection and training implications to be drawn from equipment and procedures;

c. To develop techniques that will permit the system developer to derive equipment and procedural implications from personnel data;

d. To describe system development processes in detail and how Human Factors inputs are utilized;

e. To determine what system developers need to know (from a behavioral standpoint) in order to do their jobs;

f. To determine how personnel subsystems change as the man-machine system ages.

12. Because of their psychological training most Human Factors researchers pursue research topics more appropriate to the individual orientation of Psychology than to Human Factors. Researchers have a tendency to promise to achieve more than they can. As a result, much Human Factors research concentrates not on the possible, but the improbable.

13. It is possible to taxonomize and to understand differences among systems in terms of a concept called "indeterminacy." Indeterminacy in man-machine systems is defined in terms of input characteristics, procedural variability and response programming.

14. Because of the close connection between phenomenology and much behavioral research, many conclusions derived from Human Factors research appear to be obvious.

15. One criterion of effective Human Factors research is that its data can be communicated in handbook form. The development of such handbooks is not easy, however; it requires:

- a. Determination of which system developers will use the handbook;
- b. Specification of the problems with which the handbook will deal;
- c. Gathering and selection of only those data that will answer these problems;
- d. Presentation of the handbook material in the form of "design prescriptions."

#### CONCLUSIONS AND RECOMMENDATIONS

It would be useful for the further progress of the Human Factors discipline to examine and debate the above hypotheses.

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## INTRODUCTION

The reader has probably scanned the Table of Contents, but it may be helpful if I attempt to integrate the individual topics to be discussed. The essays in this volume consider a number of topics that should be of interest to all Human Factors (HF) specialists:<sup>1</sup>

- What is HF? Or, to put it in more detail,
  - How do we define what we do as a distinctive discipline?
  - What are the goals of that discipline?
  - What are our basic assumptions and their implications?
  - What behaviors do we attempt to study?
- How useful is HF? That is,
  - What are our outputs?
  - Who are the consumers of these outputs?
  - How relevant are these outputs to what consumers consider to be their problems?
- Is HF methodology adequate for the problems to be solved?
  - What questions are asked of our discipline?
  - Are these questions meaningful and answerable?
- What are the major HF research problems that must be solved?
  - What methodological difficulties do we face in performing research?
  - What criteria should be used to evaluate our research effectiveness?
- How should HF information be communicated and to whom?

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<sup>1</sup> A short glossary may be of value here. Throughout these essays I have abbreviated Human Factors as HF. The abbreviation MMS and the term "system" are commonly used to refer to the "man-machine system."

The term "HF specialist" which is commonly used throughout these pages is hard to define precisely. Theoretically it should encompass everyone whose work on the development of the system involves the personnel who will operate and maintain that system, not only the human engineer customarily associated with equipment design, but everyone else who has responsibility for determining the nature of the personnel subsystem. Nevertheless, there are many working in system development (e.g., engineers, planners, logistics specialists) who fit the definition but who do not think of themselves as personnel specialists.

The HF specialist is also the researcher whose studies and experiments are specifically directed at solving problems related to personnel subsystem factors, or whose research can be directly applied to those factors. The latter part of this definition may also be too broad. Many psychologists perform research whose outputs can be applied to the development of the personnel subsystem; but they probably think of themselves as psychologists rather than as HF people.

Some of the following essays attempt to narrow the field somewhat, but hard and fast distinctions cannot be made. Perhaps the best definition is this: an HF specialist is someone who thinks he is an HF specialist; if he thinks he is something else (e.g., a psychologist) then perhaps he is not. Let us therefore confine the term to those who consider the personnel subsystem to be the largest part of their responsibility.

My intention in writing these short essays is not to provide definitive answers to the questions posed (definitive answers may not exist), but to stimulate the reader's thinking about them. I hope I shall be pardoned for believing that the level of thinking about HF as a discipline is on the whole quite primitive; it badly needs encouragement, hence these papers. Whether I am right or wrong in what I have written is unimportant; what is important is to stimulate the reader to develop his own ideas about the problems discussed.

(In this connection it should be pointed out that the title of this collection--Heresies--was selected to pique the reader to open the volume in the hope of finding something unusual. It also reflects my feelings that what I have to say may not be popular with my fellow professionals.)

These essays are expressions of opinion based on my experiences (a quarter of a century). Some of these ideas will be found in books previously published (e.g., Meister, 1976) but are here expanded, organized and treated as a--hopefully--coherent whole. They reflect my own point of view and not that of any governmental agency.

One might call these mini-essays, because each one considers in very abbreviated form a single concept. However, if they are viewed in relation to each other, each essay examines a different aspect of the basic question: what is HF?

Finally, if the reader is interested in any of the ideas (either pro or con), the author would be pleased to hear from him.

**THE NATURE OF HUMAN FACTORS**

## 1. ON HUMAN FACTORS AS A SYSTEM SCIENCE<sup>1</sup>

If one can believe the terminology employed by HF specialists, our discipline is a "system science."<sup>2</sup> For example, we generally define our research as directed to the study of "man-machine systems" (MMS).

It was not always so. It is my impression that in its very early days (e.g., the late 40's and early 50's) the term "man-machine system" was not found very often in the literature. It was only in the early 60's that Christensen (1962) pointed out that HF as a discipline has followed a developmental sequence, from a relatively molecular to more molar (i.e., system) framework.

Unfortunately not everyone in our discipline takes the implications of the system term seriously; many consider it as merely one more "buzz word" to be used to cast an aura of science and sophistication around our work. If one takes the term seriously, however, the implications are highly significant. The purpose of this essay is to explore some of these implications.

The first implication is that we assume that personnel--and their performance--are merely one element in the total system (along with hardware, software, procedures, the logistics of the system, etc.). From this standpoint the system is more than any of its individual elements. It has an output (to which all of its elements contribute) which is (must be) more than the individual outputs of each of its elements.

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<sup>1</sup>An earlier version of this paper was published under the title "Where is the System in the Man-Machine System?" in the Proceedings of the Human Factors Society, 18th Annual Meeting, October 1974.

<sup>2</sup>What is a system? No one has a very good definition. Roughly--very roughly--it means an organization of elements, all serving some common purpose, in which each element functions not only individually but as part of the whole; and in which the total organization commands all subsystems. The problem of specifically defining a particular system arises because at any single level a system forms part of a larger system; so where does one stop and how can one differentiate the system scientist from one who is not? This is a matter of judgment. One does not for example have to consider the Mind of God (presumably the ultimate system) in relation to an air traffic control system. For definitional purposes it is sufficient to consider the total system as bounded by those elements producing inputs to and receiving outputs from the organization under consideration. Anything beyond that (e.g., the weather which affects aircraft travel) need not be considered as part of the system. (For other purposes, however, weather elements might be considered part of a system.)

If this is true, then the fundamental questions which HF research must answer are: how does the personnel subsystem element contribute to the overall system output; how do personnel performance variables affect the system output; how do the other (non-personnel) elements affect personnel performance; how does one determine from overall system requirements and from non-personnel subsystem elements how the personnel subsystem should optimally be developed, and of course, vice versa?

Since these questions all involve the system, they can be studied only in a system context. (What constitutes the system context is defined in later essays.) The subject matter for our research becomes the system and individual (or team) operator performance within that system. This does not mean that we cannot study individual operator performance in a non-system context (e.g., in traditional laboratory settings using such non-system mechanisms as reaction time equipment, tachistoscopes, etc.) but it does mean that every conclusion derived from non-system studies (the great majority of studies we have presently) must be verified by a study in a system context.

Is this too extreme? Obviously, if we cannot believe any principle derived from non-system sources without verification, it multiplies our research requirements. But consider. Can we honestly accept laboratory findings on individuals as being valid for the performance of those individuals when they are part of and encompassed by systems that may be large and highly complex? To do so would be to assume that the system exercises no effect on its subsystems (which would contradict the definition of a system). This effect of the system may in many cases be minor, but in others may be major; in no case then can potential system effects be ignored.<sup>3</sup>

In developing experimental situations to test hypotheses, therefore, we must, if we work in the laboratory, simulate the type of system to which we anticipate our conclusions will be applicable, although this may not be easy. (In another essay (11) I explore the difficulties involved in simulating systems in the laboratory.) It is sufficient in this essay to say that the essential characteristic

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<sup>3</sup>From this standpoint, one of the major functions of HF research is to determine the extent to which conclusions derived from individual-oriented (i.e., psychological) research can be generalized to the performance of system operators.

of the system simulation is that it contains a product or output that involves more than the personnel output. This permits the testing of the fundamental HF research question referred to previously: the relation of personnel performance to system output.

To accept the system orientation is thus to reject in large measure (as incomplete) the available behavioral science literature, since most of it was performed without any system context.<sup>4</sup> The rejection need not be total or unchanging; the studies can be accepted to the extent that their results have been verified in an appropriate system context. Without such verification, however, the results presented by these studies are suggestive only, to be used as working hypotheses, perhaps, but not more.

The system orientation also requires us to deal with problems that involve massive man-machine systems. MMS may vary in size from the individual operator at one console to systems involving hundreds of personnel and masses of equipment, e.g., a ship, or a regiment.<sup>5</sup> When such systems are very large, they cannot be studied in conventional ways, such as the classic laboratory setting, and it may even be difficult to work with them in the real world. This may force upon us as researchers different (although not necessarily more advanced) techniques in dealing with such systems. Essay 11 considers the methodological problems involved.

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<sup>4</sup> By this I mean that there were no elements other than the individual and his stimuli in the test situation; the subject's responses did not interact with other test elements nor were they transformed into a product different from those responses. For example, a study of the individual's ability to discriminate stimuli as a function of a gradually increasing input rate would not be considered as a system study unless his responses interacted with or affected other study elements and these were all directed toward a goal other than the discrimination itself.

<sup>5</sup> If the operator at his console is self contained, so that during the performance of his task inputs from other (non-console) elements do not affect his responses to console stimuli, then one can deal with the operator/console combination as an individual system. If in the immediate performance of his task the operator is affected by non-console elements, then one cannot deal with him except in interaction with those non-console elements. Or, rather, one can study his performance independent of these elements, but then the study is not system-oriented and the conclusions derived cannot be generalized (without verification) to his performance in the actual system.

Finally, if HF is the science of the MMS, then one cannot consider HF as merely a special branch of Psychology, because, as explored in essay 5, Psychology is the science of the individual rather than of the system. The traditional methods of research which are largely derived from Psychology can no longer be accepted uncritically; they can be accepted only after testing them to determine if they provide meaningful and useful results in a system context.

There will undoubtedly be widespread opposition to this distinction between HF and Psychology, since most HF specialists (at least of my generation) were originally trained as psychologists and then drifted into HF. Moreover, the behavioral literature HF people refer to most is a psychological literature. Nevertheless, if one accepts the system orientation of HF, strict logic requires the distinctiveness of HF. This does not mean that all we have carried over from Psychology is false or useless; rather it is insufficient and must be complemented by techniques and data stemming from the new framework.

## 2. ON HUMAN FACTORS ASSUMPTIONS AND THEIR IMPLICATIONS

How many of us are aware of the assumptions underlying HF and their implications for methodology?

These are rarely described or discussed, although I have attempted to do so in my latest book (Meister, 1976). When brought to the reader's attention they may not appear remarkable at all, perhaps because he has been operating (albeit largely unconsciously) with them all his professional life.

In the following paragraphs the assumption--underlined--will be followed by a discussion of its meaning and implications. Please note that the assumptions are interactive and overlapping.

1. A man-machine system (MMS) consists of a man (or men), the machine(s) and the environment, the total organized as a system. Everyone knows what men and machines are, but the environment is not clearcut. In this definition the environment, broadly conceived, includes not only the physical task setting but also operating procedures, job aids, tools, supplies, etc., in fact, everything that cannot be ascribed to either man or machine but which supports them.

No one would seriously contest assumption (1). Nevertheless, a question that often arises is how one concretely defines the MMS. When humans use tools as an aid in accomplishing a goal, does the combination form a MMS? If so, the definition becomes meaningless, since almost all behaviors are mediated with the aid of what can be described as a tool. Even apes have been observed to break off a twig or tree limb to prod a honey cache. No, although the human/tool interaction forms a man-machine relationship (a more primitive organization than a system), it is not a system.

Three criteria differentiate a MMS from a man-machine relationship. A MMS exists only when:

a. The machine exerts a reciprocal effect on the man as a consequence of the latter's activation of the machine. The output of the man must be transformed by the machine; likewise, the machine output must be modified by the operator.



In this respect then their combined output is different from that of either one. This stems from the fact that in a true system any two elements influence each other so that each is slightly modified.

b. The machine must be able to function (once activated) independently of the man. Any system element must be able to function quasi-independently.

c. Moreover, both man and machine must serve a common purpose and their activities must be subordinate to that purpose. This stems from the fact that any system element must be subordinate to the overall system purpose.

Any man-machine interaction that does not satisfy all three criteria cannot be considered a MMS.

When a man cuts a loaf of bread with a knife, the man-knife combination does not form a MMS because:

a. The knife does not on its own perform in such a way that it exercises an effect on the man's performance. If, in the example, the knife is badly designed, it may affect the man's cutting, but this effect does not occur as a result of the man's activation of the knife. A tool is that which is operated upon but which does not operate on its user. A machine in a system not only is operated by a man but by its output affects the man's behavior.

b. The knife obviously cannot perform independently of the man.

c. The man is not subordinated to the same purpose which the machine serves, or at least not to the same degree; he can always decide not to cut the bread, or to tear it apart with his hands. His task is not determined by a superordinate authority (e.g., a boss, a commanding officer) but by his own will.

The reader will perhaps ask why one should be so precise, so punctilious, about what appears to be a mere technicality. It is, however, a crucial distinction, because it bears upon what we can extract from the general behavioral literature that may apply to the system context.

Many psychological studies make use of man/tool situations; these fail, however, to satisfy the three system criteria. For example, suppose an experimental situation in which the subject's task is to discriminate visual stimuli (e.g., geometric symbols) presented on a CRT; the subject records his judgments by depressing one or more keys which then activate the next display. This might be considered a crude parallel to a sonar/radar classification task. Does the situation accurately represent a MMS?

Does the CRT affect the subject? Perhaps, if its presentation is too dim or illegible. However, there is no transformation of the subject's responses because of his interaction with the machine component. In an actual sonar/radar situation, the operator might well modify the CRT presentation (e.g., by amplification, changing aspect) in order to aid his classification. Does the machine component (the CRT) operate independently of the subject's performance? No, in this respect it is merely a tool. In the experimental situation both man and CRT serve the same purpose; the situation therefore satisfies this criterion.

In examining this study, however, the information provided may be applicable to the sonar/radar classification problem but one could not be certain unless the results were confirmed under more realistic system conditions.

Assumption (1) therefore delimits--roughly only, of course--those data that can be immediately applied to MMS situations from those that cannot. At the same time the definition specifies the kind of situation which must be set up in order to develop behavioral principles relevant to MMS.

2. The output of the system is different from the output of any of its elements. This derives from the previous assumption that the MMS is composed of more than a single element. Since each element interacts with every other, it follows that the output of the whole must differ from the output of any of its elements.

Several implications flow from this. Since human performance and the system output are not the same, the relationship between the two becomes of primary research interest. Moreover, since the system output subsumes the human response, the former becomes the criterion against which changes in the latter are to be

assessed. Thus if a change in human performance has little or no effect on system output, that change is of relatively little importance.

3. The MMS varies in size and complexity from the single operator/console unit to large masses of men and equipment. This assumption is obvious, of course, but it is important to emphasize it, because researchers have generally preferred to confine their research to the smaller systems, probably because of convenience. The assumption reminds us, however, that we cannot ignore the larger systems which may have significant problems of their own. Indeed, it is possible that what system managers are most interested in are not subsystems of large systems, but the large systems themselves. From a cost-effectiveness standpoint it is more meaningful to be concerned about major systems than individual work stations. The point might be advanced that one cannot measure or improve systems without first measuring and improving their subsystems; but the combination of measures on individual work stations cannot equal the system of which they are a part.

4. MMS elements interact with and influence each other and the total MMS. Interaction produces change. This assumption means that whenever one combines one element with another or modifies the characteristics of one element, the performance of all other elements in the system and of the total system is affected. The effect may be slight or it may be great, but it exists. The amount and quality of the effort can be determined only in relation to total system output. If total output is changed substantially, the effect is great; otherwise not.

The importance of this assumption is that it assumes that all elements in a system (however one defines that system) are related. The task of traditional hypothesis testing is to determine at what point or under what conditions the relationship is substantial.

If the assumption is granted, it is not sufficient merely to perform a study to determine that a significant relationship between two or more variables exists. If one assumes in advance that the relationship exists, the purpose of testing is to determine when the relationship is significant. This suggests the necessity of a data base which is defined as data describing the complete range of interactive effects between two variables. Traditional hypothesis-testing typically samples across the range of these values. A data base fills in the gaps left by hypothesis-testing.

For example, suppose the two variables being studied are (a) number of displays and (b) speed of operator scanning of these two displays. It is unnecessary to test that there is a relationship (simple observation enforces this conclusion). What is needed is a study that reports a scanning speed for each display number, the result of which will be a table relating 1, 2, 3 .... n displays to their corresponding scanning speed.

It will be objected that the task this imposes upon the researcher is insupportable, because it demands many more data points and hence more studies than traditional hypothesis-testing requires. And of course this is correct. Yet the nature of the system development process requires more comprehensive data than one secures from merely attempting to determine a relationship. One cannot merely tell the system developer: reduce the number of displays as much as possible because operator scanning speed is inversely related to number of displays. This information tells him little or nothing. To act on the relationship he must know how many displays he can include before operator scanning speed is unacceptably reduced. For this information one must know the number of displays producing both acceptable and unacceptable performance.

Most researchers would accept assumption (4) but few perhaps would explore its implications to the conclusions I have drawn, perhaps because traditional hypothesis-testing is so firmly established as a research paradigm.

5. The MMS is purposefully directed to produce specified outputs. Higher order (system) requirements determine lower order (subsystem) requirements, inputs and outputs.

The most outstanding feature of the MMS is that it is an artificial (man-made) construction. This means that the system developer can select among alternative designs. Being human, he can make (and has made) mistakes. However, because he is human he can presumably be influenced (taught) to create more efficient systems. This is one of the fundamental rationales for the HF discipline (see essay 3).

Purpose, which has been for many years denigrated by psychologists, is all-important in HF, because it directs all system development processes and one can approach it directly (via the developer). Since higher order requirements

influence lower order ones (in Christmas tree fashion), design is inherently logical (bound by relationships), but it is human logic with all its inadequacies. Because the system developer's intent is distorted by his inadequacies and idiosyncracies, it is important to learn how to influence him. And so a major research area in HF must be the study of the developer and particularly how he makes use of HF inputs.

6. The system functions in order to produce certain outputs specified by the developer; it is adequate only when these outputs are achieved. Because these outputs serve as criteria of system efficiency, it is relatively simple to determine when and by how much system and personnel performance miss optimum (their design/performance goals). This is in contrast to individuals performing in a non-system context, whose criteria of efficiency are often imprecise and relative. However, just as in the human homeostatic (i.e., feedback) mechanisms are necessary in order to adjust system activity to accomplish the required output. System feedback mechanisms differ substantially from those utilized in training (see Meister, 1976) and require distinctive research.

7. The MMS functions in both space and time and is affected by both. Obviously MMS (e.g., ships, aircraft) move through space and changes in the environment produced by their movement can seriously influence the MMS. It is accepted that systems function in time (after, MMS age as do other organisms), but what is less apparent is that these time changes can also impact on system functioning and efficiency. As hardware ages, equipment reliability decreases and malfunctions tend to increase. This increases the frequency and range of required troubleshooting. Similarly, the operator's performance changes over time because of fatigue, satiation, learning. Because of this, the system as it functions in operational life may be different from what it was immediately after it entered upon that life; and the more complex the system, the more pronounced these changes are likely to be. Fatigue and satiation are temporary changes that influence primarily the individual operator; but the system, through its personnel, also learns when it is found that contingent output patterns successfully solve certain problems. Procedural changes resulting from experience become formalized and the system changes as its procedures change. Logically the system should be as complete and well defined as it can be after it has passed through developmental and operational testing, but it is possible that more

complex (e.g., indeterminate) systems are "born" as it were with unfilled potentialities. In early life the precise nature of inputs may not be known and there may be many more contingencies; such systems may "mature" and become more determinate through learning processes which may differ from those of the individual. The area of system learning is one to which HF researchers would do well to address themselves, because of the potential value in determining precisely what these learning mechanisms are.

8. All subsystems (including their functions and outputs) must contribute to total system output; those that do not are inefficient and must be modified. The feedback mechanisms referred to previously are used to optimize input-output relationships (within design limits, of course). All subsystems (including personnel) are subordinate to the overall system goal. One can infer from this that all personnel considerations that do not materially contribute to the system output are irrelevant and should be eliminated. Logically then factors such as motivation and incentive should be ignored, but practically one cannot because lack of personnel satisfaction can significantly degrade system output.

Few systems are as efficient in operation as they were in conception. One can hypothesize that as soon as systems are turned over to their operators a very significant loss in efficiency is experienced and this loss occurs mainly in the personnel subsystem. Whether this is in fact so, and if so, why, requires longitudinal studies of systems extending into their operational stage.

It is no use saying that systems go wrong because their developers are human and thus error-prone, because such a statement simply implies resignation to an unsuitable state of affairs--which may not be immutable. What are needed are in-depth, historical studies of how various systems were developed and where they went wrong. However, few such studies have been performed; they embarrass the developer who rarely admits that anything he did was less than perfect.

The portrait of the system sketched by these assumptions is that of a quasi-biological organism; human logic, purpose and guidance pervade the system. (These latter provide tremendous advantages in flexibility of response but corresponding disadvantages in the form of irrational responses.) Nevertheless, it is probable that the MMS is more than merely a more complex form of human, to which individual principles can be applied with little change; it is highly

likely that the system as system has its own principles and mechanisms which, to be unearthed, require research as exacting as that performed by the psychologist on the individual human.

The assumptions do not unfortunately help to suggest hypotheses to be tested. It is possible to conceptualize the variables that probably affect MMS functioning (see the list in Meister, 1976), but they offer no basis for selecting one hypothesis over another as being more likely. For example, are indeterminate systems more or less efficient than determinate ones? (See essay 15 for a discussion of indeterminacy.) The lack of empirical data about systems makes it difficult even to develop hunches.

The assumptions do however indicate areas for further investigation. It may be merely an excuse to say that we need more data, but certainly we need more descriptive studies of real world systems.

## 1. ON HUMAN FACTORS GOALS AND THEIR IMPLICATIONS

It may surprise some readers of these essays that I bring up the topic of HF goals. Surely these are obvious and generally accepted?

I think not. Like the assumptions discussed in the previous essay, HF goals are taken for granted; rarely does one contemplate them deliberately and trace their implications. There may in fact be a bit of reluctance to discuss HF goals, because of their elementary, "obvious" nature.

I suspect, moreover, that, if the question were seriously raised, there would be a deep division between those who think of HF (in whatever manner they conceptualize it) as predominately a scientific (e.g., research-oriented, academic) discipline and those who view it as essentially an application of behavioral principles.

Those who think of HF as a science may feel that its purpose, like that of science generally, is to understand how the MMS functions.<sup>1</sup> Those who view themselves in a more activist role may feel that the HF goal is to assist in the development of that MMS. The differences between the two points of view become most evident in deciding what HF research should be performed, the "scientists" insisting on their curiosity as the primary criterion for what they shall work on ("pure", "basic" research); the "practitioners" insisting that whatever research shall be performed must be in response to some specified need for knowledge that can be applied to the development of the MMS ("applied" research).<sup>2</sup>

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<sup>1</sup>There may be those who object that their focus of interest is system personnel, but not the system per se. This is a misreading of fundamental system assumptions. Since personnel are an inextricable part of the system, HF must also be concerned about the system as a whole. One cannot isolate personnel from their system matrix. To do so is to approach them as individuals--which, as has been pointed out, is a grievous error in HF.

<sup>2</sup>Is no compromise between these two viewpoints possible? One would hope so, but read on.



In the best of all possible worlds there would be no disparity between the two goals. Scientists assume that adequate basic research will inevitably lead to valuable applications--and indeed in the "hard" sciences they have in the main done so. But has the greatest part of HF research led to useful applications? Unfortunately, the answer is no, and the reason is that "basic" HF research has failed to focus on the true subject matter of HF.

Before explaining what this last (and certainly most controversial) point means, it is necessary to define my concept of HF goals. Note the plural. There are two goals, equally important.

1. To assist in the development of man-machine systems.
2. To understand how man-machine systems function.

These correspond to the "applied" and "basic" orientations referred to previously. I put the applied one first because I consider it to be the ultimate goal, but manifestly one cannot assist in MMS development without understanding how the MMS functions.<sup>3</sup>

In other essays I have spoken about the MMS as the distinctive subject matter of HF. There should be no controversy about that assumption. Since MMS are developed, it is obligatory that our discipline assist in that development. Therefore the ultimate goal of HF activity is to bring the development of MMS closer to its optimum. From that standpoint, all HF research must directly or indirectly be oriented toward the solution of problems arising from MMS development.

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<sup>3</sup>The reason for emphasizing system development is that the starting point for the consideration of any personnel factor is system development. How one develops the system is so important that anything one does after the system is configured is largely (but obviously not completely) irrelevant. Manning, selection, training, performance measurement, etc., etc., are all largely determined as soon as the system is defined.

This goal need not restrict the HF researcher. System development in its broadest sense requires not only hardware design but also various analyses, items of information and data (e.g., tradeoffs between equipment configuration and personnel capability, availability, manning, selection, training, etc.), techniques for predicting human performance before developmental testing, the measurement of system performance as the system functions during operations. The scope for HF research is therefore extremely broad because it includes all the behavioral variables that enter into or may affect system functioning (see Meister, 1976).

Nevertheless, much of what the HF researcher produces for use by the practitioner is useless for the latter's system development purposes. The key factor is that many if not most HF researchers concentrate their research on the human in a non-system context, when what is needed is research on human performance as it influences and is influenced by the system of which it is a part. "Basic" HF research which is directed at the role of the human in the system must inevitably lead to useful system development "applications".<sup>4</sup>

Because of their psychological training, most HF researchers pursue research topics more appropriate to a purely individual orientation. Lacking the system context this research leads to spontaneous abortion when the HF practitioner attempts to apply it to system development problems. This is not to say that the data produced by this research are invalid, since any properly performed research must produce valid data. However, HF research attacking topics irrelevant to MMS development must inevitably produce data irrelevant to its needs.

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<sup>4</sup>Some specialists may feel that research on the MMS is, because of its subject matter, invariably applied. To controvert this attitude I must emphasize that basic research on the MMS is not only possible, it is in fact absolutely essential, since the system represents a domain for the human different in many respects (some of which have been described in other essays) from the human in a non-system environment. Hence so called "basic" principles of individual functioning do not necessarily generalize (apply) to the system. An example of a basic HF research topic might be the general question of how feedback functions in the MMS (a question discussed in Chapter 6 of Meister, 1976). An applied HF research question might be the number of colors that could be used for feedback purposes in MMS displays.

If HF research is necessary to produce the data needed by HF practitioners, that research must be directed at questions implicit in MMS functioning and development. HF research is research specifically on how the human functions in the MMS context, not research directed at humans in terms of general variables. The latter is more properly performed by psychologists who are not concerned about the MMS. Obviously data on how humans perform in non-system contexts are important in terms of providing a basis for understanding how they perform in the system (in much the same way that a knowledge of chemistry is important for understanding biological processes). However, the HF researcher who expects his research to be meaningful in HF terms must always be aware of the importance of the system context. When he applies research in that framework, there is no conflict between basic and applied goals, since there are basic (fundamental) MMS questions as well as applied ones.

The implications of the point of view expressed in this essay are that:

(1) Much of the research in the available behavioral literature is insufficient for HF goals as described here, because it is performed in a non-system framework.

(2) In order to incorporate the system into HF research it is necessary either to simulate the system as the framework of that research or to gather data by observing real world systems. In order to simulate systems in a laboratory setting it will be necessary to apply the MMS criteria described in essay (2), to develop situations in which subjects perform tasks whose outputs act on and are acted upon by other subsystems so that one can observe the effect of one subsystem on the other and on an output which summates the two or more subsystem outputs. For example, one might wish to study the effect of varying input data rates in a system in which one subsystem receives the data, processes it and then inputs the processed data to another subsystem that transforms the processed data into a different form. It is not necessary to create hardware to develop such system situations. Operations that would ordinarily be performed by hardware can be simulated by computer or by experimenter actions. The important thing is that parts of a system act on each other and that their individual outputs are integrated to be output by the simulated system as a whole. Behavioral variables in a system context are necessarily more complex than they are in a non-system setting; consequently, the experimental setting must likewise be more complex, although it need not be electro-mechanical.

The inadequacy of much basic HF research to assist in MMS development results from the researcher's failure to understand the overriding importance of the system framework in his research. This failure produces research much of which is irrelevant to underlying HF concerns. As a result, the HF practitioner fails to receive the data he needs and is retarded in his efforts to assist system development.

#### 4. ON HUMAN FACTORS AS AN ART FORM

From time to time one hears a HF practitioner, i.e., someone who applies HF principles to system development, assert that HF is an art rather than a science. More often than not--and this is what is most surprising--he says it almost proudly. Presumably he means by this that HF in system development depends primarily on the expertise, the learned but undefinable and largely idiosyncratic skills of the HF specialist, rather than on explicit principles and data.

Certainly such expertise is a necessary factor in applying HF to system development. Nonetheless, to deny that HF can be more than art is really a confession of failure, because presumably our goal is to make our discipline more rather than less scientific. Of course, the statement is usually made of HF only in the context of system design; nevertheless, since HF research is directed toward the optimization of system development, such an assertion if true perils the entire discipline.

Our goal as scientists--even those who work in system development--is to make our work more scientific, by which is meant, more logical, systematic and quantitative. If the application of HF principles to system development is indeed more art than science, it is because the basis for science--properly executed research leading to quantitative principles and data-- is seriously lacking. If the data HF researchers produced were adequate to the system developer's needs, then the only expertise in HF practice would be that of applying logic and data.

It may be said that system design itself is no more than creative (= undisciplined) problem solving and hence HF applied to that design must also be creative. True, system design is creative because it constructs that which did not exist before; and if the HF practitioner were also to construct designs, his output too could be considered creative--an art form. But most HF in system development is not creative. Rather it is analytic and evaluative, its material almost always the engineer's designs. From that standpoint HF is not creative. On the contrary, if HF analysis and evaluation are to be effective, they must be logical and quantitative. Which is why the HF practitioner needs not general principles but detailed data bases.

As I said, a very great deal of HF in system development involves evaluating proposed designs to determine that they do not exceed operator limitations. If, for example, the designer asks the practitioner: is this layout (drawing) adequate from a HF standpoint, the latter should be able to analyze that layout in terms of required functions (e.g., control activations, display scanning) and then apply Human Reliability data (probabilities of task accomplishment) to these elements. The end result of the analysis would be the determination that the average operator utilizing this layout would (unless overly stressed) perform correctly 86% or 94% or whatever percent of the time. If this probability meets design requirements, then the layout is adequate; if not, then it must be modified in specific ways. In such an examination there is no room for art.

It is significant that the contention that HF in system development is an art form is usually addressed not to the design engineer, who is unlikely to be sympathetic to a subjective discipline, but to other HF specialists. Why? It is a defense mechanism, pure and simple, which enables both the HF practitioner and the researcher to ignore the great voids in knowledge and data that are characteristic of HF practice today. It permits them to overlook the fact that HF has not provided the necessary research support to its practitioners.

If it is true that in some respects the application of HF principles to system development resembles an art form, this is only because the HF practitioner lacks the principles and data he needs to do his job properly and so substitutes his personal skills. The position that what he does is essentially creative is a defensive posture which can be interpreted as follows: Please don't ask me to justify my design judgment with data; since HF in system development is an art, it is not susceptible to objective evaluation and the correctness of my judgments must be taken on faith.

## 5. ON THE DISTINCTIVENESS OF HUMAN FACTORS<sup>1</sup>

The thesis advanced in this essay is that HF is not merely applied experimental psychology or a branch of engineering, but a distinctive discipline in its own right.

Until now and at least for the foreseeable future most HF specialists have received and will receive their academic training in some field of Psychology--usually experimental or industrial. Many basic HF concepts are borrowed from psychology, e.g., the stimulus-response concept of behavior. Much of the behavioral literature on which HF depends for its data, see for example the sources of the Data Store (Munger et al., 1962) are psychological. How then can one maintain HF distinctiveness--which is to say its fundamental difference from Psychology?

The special character of HF derives from the distinctiveness of its subject matter, although there are other secondary differences (which will be discussed later). The focus of HF concern is the man-machine system (MMS) and more particularly the role of the human in that system.

Psychology on the other hand is concerned with the human and his behavior in non-MMS contexts.

It is my working hypothesis that as soon as the human becomes part of the MMS, his behavior is so affected by his interaction with other system elements that it can no longer be conceptualized in the same way as his behavior in a non-system context. As was indicated in essay 2, the concept of a system implies first that the system is superordinate to any of its elements (of which the human is one) and therefore the behavior of these elements (including the human) can be understood only in relation to the functioning (e.g., output) of the system; second, that the interaction of system elements causes changes in each of these elements such that their functioning as part of the system differs from their functioning outside the system. The existence of a superordinate entity (the system) is so significant that one cannot automatically generalize human behavior from a non-system to a system framework.

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<sup>1</sup>A somewhat different version of this paper was presented as the Presidential Address at the 19th Annual Meeting of the Human Factors Society, October 14, 1975.

One example of the difference between the system operator and the non-system individual is that once an individual enters the system, the purpose of that system controls him; outside the system, his own purpose determines his behavior. In neither case, of course, is the control absolute. The operator (the proper term to call the individual who becomes part of the system) can quit the system if impelled to do so, but this happens relatively infrequently (despite statistics on turnover); the individual in the group is also influenced by its consensus. And of course the degree of control exercised by the system varies as a function of a number of variables, including the operator's relative importance to the system mission, the number of other system personnel and the system's indeterminacy (e.g., programming of inputs and outputs).

Another difference between the system operator and the individual is that the former has the ability to exercise and modify his environment by transforming stimuli and responses into system outputs through processes that occur across what is commonly called the "man-machine interface" (although it ought more correctly to be termed the "man-environmental boundary"). This environmental modification enlarges the operator by expanding the scope of his stimuli and responses.<sup>2</sup> In the individual or the group any transformations that occur do so largely within individuals and their internal environments; there is no major external environmental modification such as one finds from manipulation of system processes. Stimuli and responses function only within the individual and modify only the individual; inputs and outputs emerge from and enter into the environment or world space outside the individual. By transforming stimuli and responses into inputs and outputs the system extends the operator by expanding his world space.

In another essay a distinction was made between the man-machine relationship, i.e., the relationship between the operator and his immediate work station, and the man-machine system. The former is more molecular and primitive than the latter, in which the focus of interest is the relationship between the operator and the total system. An applied psychologist may work with the man-machine relationship. A HF specialist will work with both the man-machine relationship and man-machine system.

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<sup>2</sup>Control over his system environment gives the individual power he does not ordinarily exercise in a non-system environment (although of course there are other sources of power he can tap in the latter).



Consequently we have two disciplines, related certainly, but functioning more or less independently.

The characteristics that differentiate HF from Psychology are summarized in Table 1 below.

Table 1. Differentiating Characteristics of HF and Psychology

<u>Parameter</u>	<u>HF</u>	<u>Psychology</u>
Environment	Expanded	Restricted
Behavioral Units	Inputs-outputs	Stimuli-responses
Organizational Units	Operator/team/system	Individual/group
Locus of Control	Function (system-specified)	Behavior (indiv. spec.)
Purpose	Specified in advance	Unspecified but inferred
Scope of Interest	Man-machine relationship Man-machine system	Man-machine relationship only

If HF is not Psychology, neither is it Engineering, since the MMS is, despite the hardware which is one of its outstanding elements, a quasi-biological entity controlled by the operator. One cannot treat the operator, except in terms of measuring his outputs, as simply equivalent to a hardware component, e.g., a switching circuit or an amplifier.

It may appear as if the distinction between HF and Psychology--or rather what is more important, between a system-oriented and an individual-oriented discipline--is pragmatically unimportant. If it were no more than a matter of what we call ourselves,<sup>2</sup> one could agree with this caveat. What we think of ourselves, however, determines the direction we apply to our work, defines the questions we endeavor to answer and determines ultimately whether or not we will be successful in solving our problems.

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<sup>3</sup>There has been a continuing debate for some time about whether we should call ourselves HF specialists, HF engineers, Human Engineers, Biotechnologists, Ergonomists, Engineering Psychologists, etc.

The distinction between HF and Psychology has significant implications for the way in which we perform our research and application responsibilities.

For example, in contrast to the individual who is born (and whose inherited characteristics the psychologist can do nothing about), MMS are artificial creations; they must be constructed. From this time it follows that the overriding goal of HF specialists must be to assist in that construction (i.e., the system development process). This is so because the HF specialist can do something about system development. If the MMS is the subject matter of the HF specialist's research, and if he can influence that subject matter, he is obligated to do so. Since system development determines man-machine functioning, failure to influence that development means that the specialist relinquishes control over the variables of greatest interest to him. As a consequence HF must be activist in the sense that its actions must be directed toward intervention in system development. A critical criterion therefore of the effectiveness of HF research and application is whether it assists materially in system development. Psychology is no less activist, but its intervention is in developmental processes following birth (like training, resolution of mental problems, etc.).

Because the system is purposefully developed to perform certain functions to specified standards, it is relatively easy to determine whether the system output meets those standards. The impact of an operator variable can be readily ascertained by determining whether a change in the value of that variable produces a change in the system output. If it does, the value of that operator variable is important; if it does not, the value of that variable is unimportant.

If, for example, excessive noise affects the operator's comfort but not his output, the noise variable becomes relatively unimportant for HF, although it may be quite important for Psychology. This is another critical difference that distinguishes HF from Psychology. The criterion of importance for the former is the system; for the latter, it is the individual. (This does not mean that the HF specialist would ignore the hazardous effects of excessive noise, because ultimately these effects would damage the system. However, short of these extreme conditions, the effect on the system would be the primary HF criterion.)

Purpose takes on an entirely different significance in HF. Whereas in Psychology teleology has generally been denigrated because of its post hoc nature, purpose is central to the MMS, because the system is developed to implement a purpose stated before the system is developed. The system developer's purpose and the manner in which that purpose is implemented in development thus become legitimate topics of HF investigation.

If one applies to HF research the necessity of assisting in system development and operation, the questions that stem from the system orientation, two are most important. First, what is the effect of operator performance on the system; second, what is the effect of other system elements on operator performance? These two fundamental research questions are peculiar to HF.

When examined in detail, present behavioral research and available data do not answer these questions. Collectively the mass of potentially relevant behavioral studies seems overwhelming. When, however, this research is analyzed in terms of system variables, it is disconcerting how little data there are. In examining the effect of the system on the operator, the system is the independent variable and the focus of measurement is on operator performance. In examining the effect of the operator on the system the operator is the independent variable and the focus of measurement is on the system output. How often does HF research vary systems and system characteristics? How often does it measure system outputs like fuel consumed or units produced?

To perform research in a system orientation requires as a minimum:

(1) Mission-oriented tasks. Such tasks are performed to accomplish an output, in which the task is only an implementing process. Such tasks involve the transformation of the individual operator's responses into an output or product different from those responses. As indicated in essay 3, this need not involve the utilization of masses of hardware. The minimal characteristics of a system exist when one operator's responses are taken by a second and transformed with or without the aid of equipment) into a product different from the responses of the first.

(2) In the development of experimental systems it is easier to establish a system orientation when real world tasks or meaningful analogues of such tasks are used. This means that part-tasks which are individual-oriented (e.g., measurement of reaction time to individual stimuli) are not appropriate.

(3) Measures of system output as well as of individual operator performance are needed, so that the effect of the latter upon the former can be ascertained.

(4) Subjects who are well trained to perform their tasks. Studies centering around the learning of a task are not particularly relevant to systems that function (presumably) with trained operators.

The conclusion to be derived is that the available behavioral literature, which is almost exclusively performed in an individual orientation, is unsatisfactory for HF purposes, no matter how useful it may be for Psychology<sup>4</sup>. Although it is tautologous to say so, it must be emphasized that the lack of system-oriented behavioral research stems from the fact that most researchers utilize an individual-oriented approach. By this is meant that their primary interest is in the individual's responses to stimuli, in what happens to and within that individual, rather than how operator responses are transformed into system outputs. Research which is individual-oriented cannot solve problems that are inherent in the nature of systems.

This is not to say that HF specialists should or can ignore psychological principles in their work. Psychological variables such as input factors, feedback and motivation are undoubtedly important in systems. However, these variables must be studied in a system context.

Despite the distinctive problems and methods of HF, the influence of Psychology over HF cannot be gainsaid. University psychologists have first crack at most of the students who will later become HF specialists. Even the specifically HF courses of study being developed in greater numbers are heavily oriented toward the individualistic framework.

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<sup>4</sup>Attention should be drawn, however, to the studies performed for the Air Force at the Ohio State University between 1955 and 1968, e.g., Kidd (1959, Howell 1967 and Briggs 1967).

What is to be done about this situation? It would be overly sanguine to predict immediate improvement. At most one can point out the realities of HF work and urge those who are committed to their discipline to keep their eyes firmly fixed on the goals of that work.

## 6. ON SYSTEM DEVELOPMENT

System development is naturally of great concern to HF because one of the major goals of the discipline is to assist in MMS development.

There is another reason, however, why the HF specialist should be vitally interested in development, a less serious but still impelling reason. Development is inherently fascinating because (despite the fact that the specialist's role in that development is usually analytic and evaluative) it is a prodigious act of creation comparable in many ways to the painting of a picture, the writing of a novel or the composition of a concerto.

In both settings--artistic creation and MMS development--one begins with no more than an idea, a goal and some techniques for implementing these. In both one finds intense problem solving, a high order of decision making and human flaws. In both the consequences of correct or incorrect choices may produce successes or failures. The development of an artistic work has been likened to the birth of an infant, and the same is true of system development. Development is comparable to the gestation of the fetus, but whereas fetal processes are biologically determined, those of the system are learned and logical. In our technological civilization the development of a major system (e.g., the aircraft, television, etc.) may be of the greatest consequence to all of us, more so than the birth of most children.

All such weighty considerations aside, system development is inherently fascinating because of its game-like characteristics. The attempt to achieve a specified goal, the alternative routes one has to accomplish this purpose, the need to trade off means against requirements, the pressure of deadlines, the periodic frustrations, the necessity for welding together disparate developmental disciplines, the elaborate hierarchical structure within which one works, the incremental rewards and punishments, the sheer indeterminacy of development--all make development more exciting than the games people ordinarily play (or watch others play).

Such a game is not of course for the ordinary individual. To appreciate it requires a cognitive breadth that only a few (and of these perhaps only a few HF specialists) possess. It may take a dramatist's mind to appreciate the scope implicit in a major development.

The game player cannot of course control the total game and may in fact have difficulty controlling even his role in it. That is perhaps why many HF practitioners become frustrated in their efforts. No single player dominates the entire drama and among the dramatis personae the HF specialist usually has only a supporting role.

And yet, what satisfaction when the curtain falls, when the hero of the play--the new system--rolls out the hangar or down the shipways or of the assembly line! If the system has been well and truly conceived, the curtain rises again after the house lights brighten, because the new system leads a life of its own independent of its creators. One who participates in the act of creation can feel an intense pride in his efforts, however slight.

It is this participation in the creative act that makes the HF discipline (despite the small numbers of its players) so important in representing the interests of one of the major system elements. This is why behavioral research to provide knowledge that will assist in the developmental process is so critical. Is it presumptuous to suggest that hardly anything else in the behavioral arena is as significant?

The importance of the HF role in system development is something that should be trumpeted loud and wide among HF specialists themselves and in the universities that serve as training grounds for new specialists.

## 7. ON HUMAN FACTORS SUCCESS AND FAILURE

At one time or another I have heard HF specialists discussing the question: how successful has HF been? This is not the kind of question a scientist ordinarily asks himself, because a discipline exists independently of the approbation accorded to it or the success or failure of its practitioners, and there is moreover no meaningful answer to the question; but HF with its emphasis on application to system development is not a typical discipline.

Any individual's answer to the question is likely to be determined largely by his own experiences and those who ask the question may be those who have had least success, as measured by what the world considers success: papers published, awards received, promotion, etc. Conceivably to ask the question is merely to project the object of one's skepticism (one's own performance) to doubt about one's discipline.

Nevertheless, if the question is asked frequently enough, it is reasonable to attempt to answer it.

But success or failure in relation to what? Objective criteria, e.g., the number of HF specialists employed, the salaries they command, exist (Kraft, 1969), but I prefer to ask the question in relation to the two goals of understanding how the MMS functions and of assisting in MMS development (those who do not accept these goals will find the discussion below irrelevant). This avoids the personal reference.

Let us assume two types of criteria, "internal" and "external". Internal criteria describe HF success as an intellectual "scientific" activity (e.g., researches completed, papers published, etc.). External criteria define HF success in terms of its relation to systems and system development processes.

Ordinarily in describing a science only internal criteria are used. However, because the goal of assisting MMS development is intrinsic to HF, external criteria must also be applied.



On the basis of internal criteria HF may be maintaining its own. We publish two journals (Human Factors and Ergonomics); hold annual meeting as well as meetings of the English, French, Dutch, etc. societies) and distribute a large number of reports from government laboratories including "Human Factors" (or its cognates) in their titles. On that basis it would seem that HF can hold its head up as a scientific discipline.

And yet, with regard to understanding how the system functions, we know very little, primarily because, as was pointed out in previous essays, studies dealing with actual systems or involving system simulations are rarely performed. Many papers dealing with worker productivity, motivation, communications, etc., are published, but the focus of these studies is on the individual worker and not the behavioral factors affecting the system. Data about how systems qua systems function behaviorally are sparse. Nor do we know a great deal about how the behavioral elements of systems are developed, although reports have been written to describe how systems should be developed, (e.g., Folley, 1964). Unfortunately, since we do not know how systems actually function, we cannot evaluate these reports. It may be that the HF specialist endeavors to impose a theoretical structure on a stubborn reality that resists accepting it. Many of the tutorial works is produced by HF specialists describe system development as they would wish it to be rather than how one suspects it actually is.

With regard to data describing specific relationships among man-machine variables, there are relatively few. One need only examine in detail the literature on any variable to find that its data are highly restricted and conflicting. There are exceptions, of course; there are many more data describing molecular man-machine functions, e.g., detection and tracking, than there are describing more molar functions, e.g., decision making and feedback. The reason is that the more molar functions require studies involving a broader system context.

With regard to external criteria and the goal of assisting MMS development, systems are still being produced with such childish human engineering inadequacies that they would be laughable if their consequences were not so grave. To give illustrations of such flaws would extend this essay interminably; for examples, talk to any experienced HF practitioner.

Such flaws are all the more amazing because in many cases the use of common sense alone should be all that is necessary to avoid such problems. One may ask why the past 30 years of tutorial HF reports and continuous contact between practitioners and designers has failed to make much of an impression on the latter. Since there have never been enough of them to the job properly, over the years practitioners have made major efforts to indoctrinate designers to apply the simpler HF principles on their own.

This tutorial function is perhaps the most important activity the HF practitioner can engage in.

The possible causes of the failure to leave a lasting impression on engineers are difficult to specify, or perhaps several causal factors are responsible: the typical engineer's indifference to behavioral factors; development management's lack of concern for HF; the failure of government monitors to ensure that human factors are considered in systems being built for them. The HF discipline itself is not without responsibility; it has not provided an adequate data base to the practitioner to assist him to perform more effectively.

On the other hand, if one considers how systems would be developed in the complete absence of a HF discipline, we have had at least minimal success. It is popular concept among HF personnel that if one were to extrapolate present system development inadequacies to a situation in which there were no HF efforts, the results would be abysmal. If HF begins its efforts quite close to the zero level of human engineering adequacy, or even below, then even a slight improvement bulks relatively large. Such limited success is not sufficient to boast about, but it is enough to feel that HF assistance to system development has not been completely abortive.

Measures of HF success in system development are highly subjective, of course. It would be well nigh impossible to find data on or even to estimate the number of systems that are properly human-engineered in proportion to these that are not. There are more objective but less specific criteria, such as the percentage of the budget allocated to HF in system development (between 1-3% of total development costs), but all this criterion suggests is that the discipline does not bulk very large in the view of system managers.

All in all, the HF track record is nothing to be especially proud of, but neither has it been a complete failure. Whatever the reasons for its only partial success, they are largely beyond the power of the individual practitioner to correct. What he can do is to improve his image by doing a better job at whatever that job is. For HF researchers, increasing the chances of success means attacking more relevant research problems, collecting appropriate data in sufficient amounts; communicating these data in meaningful form to the HF practitioner who must apply them. If the HF discipline does well what it ought to be doing, it can have nothing to be ashamed of.

## 8. ON MOLAR VARIABLES IN HUMAN FACTORS

There are two strong currents in HF, the one traditional and molecular, the other more novel and molar. Traditional HF specialists (who are more likely to call themselves human engineers) have focussed directly on the man-machine interface as represented by the control panel, console and work station. Their concern is primarily with the improvement of equipment to satisfy the needs and limitations of the equipment user. Although they assist to a certain extent in creating the initial concepts of system development by performing function allocations, information; decision-making and task analyses, etc., the heart of their activity is with the relatively molecular level of the equipment interface.

On the other hand, there are those (e.g., Askren 1973,) who feel that the HF responsibility extends to all variables affecting system development, including such factors as personnel availability, skill level requirements, manning, selection, operator performance prediction, training and system performance measurement. These essays reflect that orientation.

It would be invidious to suggest that those who concentrate on molecular HF are wrong in not espousing a broader viewpoint. The nature of the MMS, however, and the demands made by governmental sponsors of HF research and development go beyond the scope of the work station. In large scale MMS the optimization of any single work station may have relatively little impact on the total system simply because that work station is only a minor part of the whole.<sup>1</sup> It is true of course that deficiencies in the human engineering design of a control panel can create serious difficulties for the entire system. Often these, however, if severe enough, are recognized and corrected, if only in part. On the other hand, it is possible that over the long run systems are more adversely affected by such subtle and less easily recognized deficiencies as incorrect decisions concerning automation. Because of the cascade effect of earlier developmental decisions (prior to design of the work station) upon later ones, these decisions render many factors affecting work station design moot.

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<sup>1</sup>This is of course not true of highly complex single operator systems such as aircraft or railroad engines, where the span of control between the operator and the ultimate system output is direct.

Because MMS are developed in the context of a supra-system (such as the national defense budget) variables impacting upon the supra-system are likely to draw more attention from system planners and managers than do human engineering variables. For example, if, in a large scale system one is able to reduce the number of required personnel by 25% or the training they require by 30%, this has significantly greater impact on the supra-system than optimizing all the work stations in that system.

In consequence governmental sponsors of HF R&D are primarily interested in those relatively molar questions; the tasks they set for HF researchers often deal with molar variables. Moreover, the more molar variables such as skill level and amount of required training play--or should play--a significant role in early system development--tradeoffs that will eventually lead to the human engineer's work station. The HF researcher cannot therefore ignore these variables.

The human engineer working in the restricted purview of his console layout may perhaps be able to ignore such problems (and he would probably prefer to do so because of their difficulty). Traditional human engineering permits its practitioners to ignore molar questions (e.g., the effects of personnel availability) because these cannot be tied very directly to the individual work place. For those focussed on the control panel the concern for measurement of total system output and the effect of system variables on personnel performance hardly arises. Moreover, since the human engineer does not deal with large scale systems in their totality, experimental laboratory methodology can be more readily applied to his problems.

But is traditional human engineering enough (in the sense of enough scope, enough opportunity, enough interest) for HF specialists? One of the newer trends in HF thinking is the push to have HF move into design of what has been termed "Socio-technical" and what I prefer to call "social-benefit" systems (DeGreene, 1973). These are systems such as city planning, fire, justice, welfare, etc. (There is a comparable drive to move into commercial systems, but I shall ignore this for reasons that have been addressed in the next essay.) There has been an understandable reluctance on the part of some American specialists (and much more among European ergonomists) to deal solely with military systems, not only for

financial reasons--the number of major system developments is limited and government procurement is erratic--but also for idealistic reasons: to do something that benefits the larger mass of "people".

Such a breakthrough into social-benefit systems demands a broader orientation than traditional human engineering because most such systems have only a limited demand for human engineering. Moreover, HF specialists interested in such systems want to do more than advise on human engineering. They want to help create these systems by applying the logical-rationalistic methods<sup>2</sup> by which military systems are developed. To do so, however, requires dealing with the more molar variables involved also in military systems.

For the HF specialist the problems to be faced in trying to develop social-benefit systems are greater than those involved in developing military systems, because there are crucial differences between the two types of systems. Military systems start with a relatively clearer, more precise statement of objectives; in social-benefit systems the objectives are muddled by politics and by varying philosophical approaches to these objectives. Social-benefit systems have "clients", who expect to receive a certain degree of satisfaction from system operations; in military systems there is no client as such, although there are system personnel whose motivation and satisfaction must be taken into account. (With the abolition of conscription and the introduction of the volunteer service, these additional considerations assume greater importance for military systems.)

In military systems the ultimate goal is performance efficiency, not client satisfaction; in social-benefit systems the goal is not only performance efficiency but also (and perhaps more important) client satisfaction. These two goals may be partially antithetical. Since the logical-rationalistic approach is directed primarily at efficiency rather than satisfaction, the methodology available to the HF specialist may be somewhat lacking.

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<sup>2</sup>The use of the term "logical-rationalist" implies that development proceeds by the selection of the most effective system configuration on the basis of deliberate tradeoffs of criteria such as cost, personnel availability and skill, mission performance requirements, reliability, etc. (This is the rationalistic aspect.) Decisions made earlier in system development for more molar system units determine decisions made later in relation to more molecular system units on a logical basis: if thus and so, then...(This is the logical aspect.)

Despite the problems presented by the social-benefit system, if our civilization continues to become more technologically oriented and governmentally controlled, one might expect increased potential for HF expansion into such systems. In order to capitalize on that demand, however, it may be necessary for the HF specialist to learn much more than he presently knows about how systems function behaviorally. It cannot be said that his assistance in the development of military systems has been completely successful. There are many reasons for that, but one is his lack of knowledge. If he is to hope eventually to assist in the development of social-benefit systems, he must do a better job with military systems.

He may also have to modify the principles and techniques he has used with military systems to meet the new requirements and to include in his area of concern some of the variables dealt with by researchers in Organizational Development (e.g., job satisfaction, motivation, organizational structure). Whatever else he does, however, he will have to adopt a broader system orientation.

## 9. ON HUMAN FACTORS AND THE GOVERNMENT

There are those HF specialists who would prefer not to work directly for the government or on military systems and who look forward to an expansion of HF influence on commercial systems and even social-benefit systems (see preceding essay).

The theme of this essay is that in this country at least there is a natural and logical relationship between the government and the HF discipline; and that because of the way industry is constituted, it is unlikely that HF will make extensive industrial inroads in the immediate future.

Only three possible sources of support exist for the discipline: government, industry or the university. For HF research (particularly of the "basic" variety) one can look only to the government or to the university, since industry subsidizes relatively little research and that only of direct value to product development. The university hardly recognizes the existence of HF, considering it only a bastardized form of applied psychology--and there is little room in academia for research in applied psychology. Thus only the government is likely to support HF research.

For HF applications to system development, one can look only to government or industry, since the university typically does not develop MMS. Again the government is the only logical choice because industrial development of non-military systems is concerned not with maximizing system efficiency or even individual operator efficiency but only with increasing sales. With few exceptions industry is uninterested in maximizing personnel efficiency because its systems do not compete with each other on the basis of efficiency. Moreover, the typical consumer buys not on the basis of relative system efficiency but because of factors such as advertising, appearance and cost--all essentially irrelevant to HF. Then too a good deal of industrial development does not involve systems, but rather products, e.g., tools (see essay 2); and for these the services of an industrial designer would probably be more appropriate than those of a specialist. Only military systems require that efficiency (in which the human element plays a critical role) be maximized because in a combat situation only the more efficient system will survive and win.



HF plays a role in industry, of course, but it does so only when the government insists on it, as in military system development; or in industries that are controlled or closely monitored by government, as in aviation or telephone communications. Even when it pays for HF assistance in the development of military systems, the government has great difficulty persuading industry to accept the notion. This does not bode well for HF participation in commercial system development, where HF costs come from overhead funds.

One cannot therefore look forward to any early HF advances into commercial industry. On the contrary, HF specialists ought to be grateful that the government gives them the opportunity to perform their work.

But is HF solely a military occupation? Not necessarily. In non-military governmental systems (social-benefit systems like justice, welfare, city planning), the opportunities for HF will certainly be greater in the future, but for reasons I have explained in the previous essay, and in an earlier paper (Meister, 1973) the HF discipline may have difficulty adapting to the special demands of these systems.

The dependence of the HF discipline on the government is therefore quite natural. (The relationship is no less important to the government, because of the severe system inadequacies that would result from lack of HF attention to system development; but for obvious reasons the dependency is on one side only.) This does not mean that the relationship is entirely satisfactory to HF specialists because (1) the amount of financial support the government extends to HF, whether in research or in system development, is absurdly small, compared to the sums it expends on hardware and hardware-related disciplines; and (2) the government's understanding of the importance of HF for efficient system design, although greater than that of industry, is still fairly meagre.

It was no accident that HF as a distinctive speciality arose out of the technological explosion of World War II. Had that explosion occurred under industrial control, it is quite possible that the development of HF would have been aborted.

## 10. ON SELECTION AND TRAINING AS SYSTEM VARIABLES

It would be incorrect to assume on the basis of the previous essays that individual-oriented variables play no part in MMS development. Selection and training serve as examples of (1) the interaction of Psychology and HF in system development; and (2) how individual variables are transformed during system development into system variables.

When an individual takes a test to determine his suitability for an operator position, selection obviously functions at an individual level. When training is provided the selectee to fit him for that position, it is given to him as an individual. These are psychological functions because they relate to the individual and do not involve system considerations. How then do selection and training become system variables?

Selection as a system variable involves the derivation from system requirements together with the equipment configuration of a category of skill or aptitude for which a number of personnel (i.e., more than one) will be selected. Ideally (the procedure by no means functions so smoothly) the system developer and/or HF practitioner will say, for example, that based on system requirements 16 crewmen possessing a strong aptitude in mathematics will be needed to operate and maintain a vehicle.<sup>1</sup> The means of selecting these personnel (e.g., a selection test) are not at this point considered because these do not affect the system configuration. The test items to be used to measure the aptitude required (an individual matter) need not be considered; it is for the personnel psychologist either to develop a selection test or to find one already developed that satisfies the need. Alternatively, the system planner can (and sometimes does) say to the system developer, build a system that requires only such and such minimum of skill to operate. In this case the aptitude requirement drives the system, in part only, of course. Again, however, the selection test does not affect the system design.

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<sup>1</sup>The description of selection requirements should of course be much more detailed and specific. They are abbreviated for this discussion.

The system developer (or his surrogates, the HF practitioner or the training specialist) must also derive from system or equipment characteristics the type and length of training needed to enable personnel to operate the system. Alternatively, he may be asked to design a system that will require a minimum of training. In both cases training as a system variable involves determination of its type and duration only; the specifics of the curriculum as they apply to the individual need not be considered at this time, because they cannot affect system design.

The point of this essay is that selection and training (as well as other factors) become system variables only when they are considered in interaction with other considerations such as performance requirements, equipment characteristics, cost, reliability, logistics, etc. And then only when they are traded off against the latter to select a system configuration which is a compromise among all of them. This of course considerably simplifies the situation as it actually occurs.<sup>2</sup>

Please note that when personnel variables are considered in interaction with other (non-personnel) variables, the former become relatively abstract; thus, the question becomes whether the system can afford to require highly skilled operators or can utilize less skilled ones, rather than the development of a specific selection test.

After the developer decides upon the (presumably) final system configuration, decisions involving personnel variables are implemented at a less abstract level (the development of selection test items and a specific training course), at which time selection and training become individual-oriented functions with which the personnel psychologist or training specialist can deal. Indeed, if the configuration has not been fully defined, it would be impossible to develop an effective curriculum or an appropriate selection test. The point is that after the system configuration has been defined, personnel variables are automatically attuned toward the individual.

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<sup>2</sup> Ideally and logically in tradeoffs to select the optimal design configuration (i.e., the process of choosing design A against design B) the developer should weight selection and training as highly as producibility, reliability, cost, etc. In practice he rarely does so for various reasons: he does not consider them important enough; but just as significant, he lacks techniques for trading off personnel variables against engineering variables.

To sum up: selection and training are system variables when they are considered in interaction with other system variables to assist in deciding on the final system configuration. After that configuration is frozen, selection and training become individual variables to implement the system configuration.

Obviously there is a role for the non-system-oriented specialist in system development, but only following definition of the equipment configuration (which is of course the most important part of system development). The other side of the coin is that variables that function at a purely individual level have no significance for system development decisions.

To utilize individual variables in a system orientation requires a somewhat broader type of cognitive framework, one in which these variables are viewed as interactive elements in a system context. This is of course the essence of the system orientation.

**HUMAN FACTORS RESEARCH**

## 11. ON SIMULATION OF LARGE MAN-MACHINE SYSTEMS

The role of the HF researcher is to study all man-machine systems; not only those consisting of single or multiple operators and their consoles, but also large systems. Moreover, governmental sponsors of HF research are more interested in, for example, total ship performance than in the perennial sonar system. However, the size of large systems creates unique problems for the researcher. These problems and ways of dealing with them will be considered in this essay.

One can attempt to study systems either experimentally, (by manipulating the variables influencing their outputs) or by observation to collect descriptive data (without attempting to influence their outputs). It is however physically impossible to put a system the size of a ship into a laboratory, although one can do so with a major subsystem if one has extensive resources. It is possible to perform experiments with ships at sea (e.g., Schwartz, 1976) but the opportunity rarely occurs. One reason is that the cost of exercising a large system is usually beyond the resources of the HF researcher. Moreover, real systems have missions other than that of serving as guinea pigs for behavioral researchers. The investigator who is fortunate to find a problem important enough (in management's eyes, that is) to allow him a span of control over a system in an operational environment is rare indeed.

Lesser but still significant problems arise even if one merely wishes to observe real world system operations without controlling them. Permission to make such observations can be secured, but not easily. Often system managers can see no point in anyone observing their system (presumably because they already know all that is needed about the system).

Once permission to observe is granted, other problems must be solved. Of the many operations involved in full system exercises, which (if not all) should be observed? How can one determine in advance which are critical to system output or mission accomplishment?

The size of some large systems is such that many observers are needed, often more than is available to the investigator. For example, in the evaluation of the U. S. Navy ship Tarawa, a 30,000 ton, highly sophisticated amphibious command/control ship, no less than 91 observers were used, none of which (incidentally) dealt specifically with behavioral questions. And these observers were available only because Navy regulations required that the ship undergo operational evaluation.

There are various ways of overcoming—or, rather, attempting to overcome—these difficulties. The most obvious solution (and the one most frequently adopted) would be to ignore the large system and concentrate on single operator/console units. This however is an avoidance of responsibility. If the HF researcher is engaged to study MMS, he cannot (or should not) pick and choose his test vehicle simply for convenience. Moreover, in selecting only the smallest systems to study, he will fail to answer the special questions posed by the larger systems.<sup>1</sup>

Another solution might be select the "pieces" (subsystems) of a large system and to study each individually, ultimately building up enough data to combine them into a picture of the total system.

The main objection to this procedure is that the combination of individual subsystem tests or observations does not add up to the testing or observation of the entire system. It is true that even if the researcher tested the entire system at one time, he would still record data at the individual subsystem workstation; however, in individual subsystem testing the researcher holds all other interactive subsystems constant; by in effect ignoring them for the purpose of the individual subsystem test, he gives these other subsystems a zero value in his computation (which they do not have in real life).

In testing the total system the researcher collects three types of measures:

- (1) the performance of the individual subsystem as a self contained entity;
- (2) the interaction of the individual subsystem with other subsystems;

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<sup>1</sup>What special questions? Since the smaller system is usually only a subsystem of a larger one, it is impossible to evaluate the significance of the former's performance except as one calculates it against the output of the latter. It is possible, moreover, that variables that function one way in a small system change their manner of operation in a much larger one.

(3) the output of the total system. In his analysis he plays (1) against (2) and (3) to determine the contribution to or effect of the individual subsystem on total system output. This, as was pointed out in previous essays, is a fundamental research question. Individual subsystem tests/observations do not permit study of items (2) and (3) and may also lead to incorrect measures of the individual subsystem.<sup>2</sup> Moreover, logistically the cost in terms of time to observe all subsystems individually might well be prohibitive.

Another possible solution might be to model the system in much the same way that Siegel et al (1967) have done with their ship model and thus make it more readily handled by the investigator. To exercise an appropriate model, however, it is first necessary to have performance data for major variables influencing the system. To gather such data it is first necessary to study the system--which presents the same difficulty we began with. (Of course, if one's standards of data validity and availability are not too stringent, it is possible to use secondary data sources, e.g., expert opinion, to exercise the model.)

A variation of Siegel's stochastic model is one which incorporates into the computer process actual real time personnel stimuli and responses (a so-called "hybrid" model). This involves computer simulation of major system operations; at the same time, subjects are provided with terminals that permit them to receive computer-generated outputs and to operate upon these by manually inputting other information which the computer then processes. Such hybrid simulations permit the building up of human performance data while exercising the model; in a sense the model can "grow".

Digital simulation models of the Siegel type usually simulate a specific type of system. It is also possible to simulate certain aspects of systems in general by abstracting their significant elements and modelling them by analogy. For example, much research has been done with very simple abstract models of communications networks (Shaw, 1964) in which information transmission is represented by subjects solving problems by passing messages to each other. However, such analog simulations are often so abstract they are not representative of real world systems.

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<sup>2</sup>Suppose for example one attempts to measure the performance of a minehunting sonar subsystem without measuring ship navigation. Since the minehunting ship maneuvers as it hunts, ship navigation obviously impacts upon minehunting success. To ignore navigation would then lead to only partial evaluation of the minehunting subsystem.



The simplest means of securing information about how personnel subsystem functions are performed is to ignore hardware operations entirely and merely present realistic system stimuli to actual operators. The latter are then asked to describe how they ordinarily responded to these stimuli in the actual system and the factors that would affect their responses. Subjects might also be asked to describe how their responses would affect the system output.

In essence this technique extracts the operator from his system (it does not require the actual system environment) except for stimuli (which must however be highly realistic) and records his responses to inputs. It has one major limitation, however; it can be used only with input-oriented systems, e.g., surveillance systems in which subject responses are perceptual and/or cognitive; it cannot be used with systems that require continuous or precise motor responses. Moreover, it is difficult to build into the simulation the hierarchical dependencies often found in actual large systems.

One might consider the preceding method as an expanded form of the interview since it consists of asking the operator how he would ordinarily respond if he were faced with inputs presented. Or it could be considered a more sophisticated form of the Delphi technique (Dalkey and Helmer, 1963). The purpose of the technique is to secure information about how a specific, real world system functions from a behavioral standpoint. It has the advantage of using actual system operators (indeed it requires them) but it removes them from their working environment (the technique can be applied to almost anywhere). Although the data secured are subjective, this is appropriate to the type of system being studied (in which operator responses are largely covert).

It is apparent that there is no easy way of investigating large MMS. The possibilities available are (1) measurement (observation) in the actual operating situation; (2) computer, hybrid and analog simulations; (3) laboratory/interview methods. Depending on the method selected, one can use actual operators, trained (non-operator) subjects or no personnel at all. The methods may require no system equipment, devices for presenting input stimuli, or more or less sophisticated computers. The researcher has a choice ranging from experimental manipulation to controlled observation to quasi-interview methods. Each of the methods has advantages and corresponding disadvantages.

Despite the difficulties involved, the HF researcher cannot avoid his responsibility to study the large MMS. The special problems inherent in such systems present a compelling intellectual challenge to the researcher.

## 12. ON GRESHAM'S LAW FOR HUMAN FACTORS RESEARCH

To the casual observer it may appear as if HF researchers have a tendency to overinflate their research currency by promising to achieve results that they are in no position to achieve. Of course, this may well be (and probably is) true of other disciplines as well, and it may also be characteristic of our times which demand value for money received.

This inflation occurs particularly when proposing research that must be supported financially (what research does not require money?) and it is to be found not only in the contractor's proposal to governmental sponsors but also in proposals made by government research laboratories to other governmental entities. (There is no suggestion that such inflation also occurs in the reports of research accomplishments, at least not to the point of distorting data; however, interpretations of data secured are often subject to such inflation.) Whatever will "sell" a potential customer is considered acceptable, even though it is often recognized at the time such promises are made that they cannot be fully fulfilled. For example, a governmental Request for Proposal (RFP) will require a contractor to perform research within one year (the typical time period) that will lead to the solution of a problem which has remained unsolved despite best efforts for many years. The reader can fill in his own subject matter example. Mine is the development of a new and "unique" technique that will enable system managers during the conceptual stage of development to predict (with a precision of one part in 10,000 operating cycles) the performance of operators of the as yet to be developed system. The potential customer who received this RFP will blithely promise that he will indeed develop this technique even though the data do not exist and a year is obviously insufficient to do the required research.

Why do HF researchers promise such things? To sell, always to sell. To secure the support needed to employ HF personnel. One can have much more sympathy for the hapless contractor who has to try to implement his promises than for the governmental customer who ought to know better. The latter, however, also reacts to higher level pressures. In the minds of his sponsors, research which does not solve substantive problems in little more than a year can hardly be considered meaningful.<sup>1</sup>

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<sup>1</sup>One cause of it all may be governmental research funding policies which often do not permit the carry-over of funds from one year to the next.

Another reason for the overinflation of research promises may be a sort of defensiveness which does not permit the HF researcher to admit that he can fail at anything.

The unfortunate end result of all this high-powered selling is that it is difficult for the researcher to accomplish his promises. This leads the research sponsor--the customer--to view HF skeptically and to lose confidence in its capability.

As another unfortunate consequence, HF research tends to concentrate not on what is possible (even though restricted in scope) but on what is improbable or less possible, but which can be more readily sold to governmental sponsors. This might be called Gresham's Law of behavioral research: the need to do research inflated in conception and thus less adequate in execution prevents researchers from doing better but more restricted research. Thus, if the pressing need is carefully to build up over a number of years a data bank of how operators perform (a mundane task to some), this need is ignored in order to support research to develop predictive "models" of system performance (a task with much more panache). The only difficulty with the model is that in order to use it profitably the researcher requires the basic performance data which he lacks financial support to gather. In the meantime, as an ultimate effect, the crucial data needs of the HF practitioner go unfulfilled.

What is worst of all (from a longer standpoint) is that some HF researchers who play this game come in time to believe their own improbable assertions. The cycle thus tends to perpetuate itself.

What is to be done about this? It would be the height of naivete to believe that anything one could write about this problem would change the situation materially. And yet an awareness of what researchers do to themselves may help in time to create a more sane approach. If we think of ourselves as scientists, can we do anything less?

### 13. ON PHENOMENOLOGY AND HUMAN FACTORS

I am led to the ideas in this essay by an experience that is becoming (for me at any rate) more and more common: I examine a conclusion derived from one or more HF (or other behavioral) research studies and say to myself, is this not self-evident? Why is research needed to confirm what appears to me (and by extension I suppose to others) so obvious? For example, as the number of controls and displays on a control panel increases, the probability of operator error increases. Or, as the rate of stimulus presentation increases, performance progressively degrades. Of course! Do these conclusions not merely confirm what one knows from direct experience of real world phenomena? Should not research produce conclusions that are unexpected or that at least confirm what is uncertain?

Does this increasing experience of *déjà vu* (the experience of, I already know this) mean that HF (and other behavioral research) tends, as some critics have maintained, merely to confirm the obvious? Does our discipline have anything novel to tell the world?

This impression of "obviousness" may be purely idiosyncratic; after many years working in the vineyards, one can be forgiven perhaps for being a little disappointed in not finding the mystical and mythical "breakthrough", the great discovery. Putting that hypothesis aside in favor of the proposition that this is a general reaction to behavioral science conclusions,<sup>1</sup> let us consider some of the implications of the experience of obviousness.

The point may be made that even if data (experimental or otherwise) tend merely to verify what is known subjectively and anecdotally, that evidence is needed, since one cannot accept raw experience without objective confirmation. It is entirely possible for experience to be partially or wholly incorrect; for example,

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<sup>1</sup>It is possible that people have a consistent tendency to underestimate how much they have learned from data. Experiments (Fischhoff, 1976) suggest that people feel "they knew it all along" even when the objective data refute that feeling. "...Results show that reporting the outcome of a historical event increases the perceived likelihood of that outcome, and that people underestimate the effect of outcome knowledge on their perceptions. As a result, people believe that they would have seen in foresight the relative inevitability of the reported outcome which, in fact, was only apparent in hindsight. Thus, they exaggerate the predictability of reported outcomes" (Fischhoff and Slovic, 1976, p.2).

the widely accepted historical stereotypes of differences between male and female capability. Since "reality" as the individual knows it is purely subjective experience, it must constantly be checked by more objective means.

The behavioral disciplines are particularly subject to the charge of "obviousness. In contrast to what are termed "hard sciences" (e.g., physics, biology, chemistry), the subject matter of our discipline is mirrored in phenomenology. By this I mean that everyone (layman and specialist alike) consciously experiences the phenomenon being investigated. He has had, for example, countless experiences of learning (or failing to learn) so that learning phenomena are not foreign to him. He has manipulated equipment of varying degrees of complexity, so that at least some of the effects of man-machine complexity are familiar to him. This is much less true of physics or chemistry. One is aware of the effects of gravitation, for example, but rarely does gravitation itself enter into consciousness. Still less is this the case when, for example, one considers molecular structures. Neural action takes place constantly within the human, but he does not consciously experience changes in acetylcholine or electrical excitation along the neural pathway.

Over time the phenomenologist integrates these experiences and derives a conclusion. It is this "conclusion based on experience" which makes him feel that research-generated conclusions are obvious.

The experiential conclusion, however, is rather general, although it may reference specific objects or events. The phenomenological conclusion that the ocean has waves says nothing about the height of waves, how they are produced, their impact force, etc. It is conceivable that the major conclusions derived

from HF research can also be derived phenomenologically, but the latter are not accompanied by data and are rather diffuse, whereas the former are specific. The importance of HF research may lie in supplying the data that put flesh on phenomenological conclusions.

Every behavioral investigator has a critic--his own consciousness and that of others--looking over his shoulder as he does his work. In consequence the behavioral investigator is constrained by his own phenomenology. It is difficult for him to conceptualize variables and hypotheses that are unrelated to his experiences. The difficulty he has in mathematicizing his subject matter stems in part from the fact that mathematical symbols are comparatively far removed from the language of his experience. Even the conceptual terms in which he speaks remain tied to a common language. Thus, all task taxonomies are verbally based. Consequently the conclusions he describes are linked in the mind of his readers/auditors with their own experiential language and give the impression of obviousness. In the same way experimental conclusions are accepted or rejected as they accord with experiential ones. Where there is disagreement, the investigator doubts his own results.

It is unlikely in the immediate future that the behavioral disciplines will be influenced less by phenomenology. Indeed one may ask whether they should. There may well be advantages to phenomenology that have not been examined --at least in the context of HF.

Among the ways of looking at the interrelationship between phenomenology and the behavioral disciplines are the following:

1. Whatever the individual believes he acts upon. From that standpoint it may be worth undertaking the discovery of the belief-stereotypes that influence his system behavior. Such stereotypical thinking has been investigated in decision making but not as it relates to systems. It is probable that the functioning of such stereotypes is considerably restricted by the operator's training and the determinate procedures of system operations, but they may exercise some influence on less determinate systems. It would be of great interest to determine how far experiential reality deviates from the objective reality (to the extent that one can measure this) and what the mechanisms producing that deviation are. This is

by no means a new idea. At one time there was considerable interest in the phenomena of visual illusions (e.g., Muller-Lyer) because it was possible to compare the objective reality of the visual stimulus with the phenomenal reality of the subject's perception. That line of study has been unfortunately largely discarded, but conceivably it ought to be resurrected, although in relation to more important topics. For example, the determination of what operators see, feel and conclude about MMS may be of great interest to us.

2. The direct experience of "reality" is presently utilized in the form of opinions from experimental or test subjects. Researchers collect these primarily where objective data cannot easily be gathered (e.g., as in estimates of "ride quality") or where it is desirable to support objective data. Such subjective data have been traditionally denigrated because they are considered unreliable, imprecise or erroneous. However, personnel are rarely if ever trained to observe "reality" carefully. It might be worth comparing the accuracy of self-reports after training with accuracy before training.

3. In another essay I have pointed out that there are situations (particularly in relation to large systems) which the traditional model of experimental control does not seem to fit. Perhaps in these situations phenomenology--if properly harnessed--would be of value.

There is a great lack of detailed data in HF and it seems unlikely that all of what is needed will be secured through carefully controlled experiments. If one makes the assumption that subjective experience is a "reasonable" approximation <sup>2</sup>

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<sup>2</sup>What is "reasonable"? No one knows. All one can say is that subjective experience must represent some approximation of an external reality. Certainly that experience does not provide a completely valid portrait of that reality; but neither does objective data. How much error is one willing to accept in data? When one accepts certain conclusions from behavioral studies, one is unconsciously accepting the error implicit in these studies.



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#### 14. ON DATA RELEVANCE

Most of the questions raised about data have focussed on their validity, i.e., whether the data "accurately" represent what exists in the real world. Unfortunately, we have no external criterion of "truth" except the data whose validity itself remains to be verified; hence the question of data validity is, strictly speaking, ultimately unresolvable. At best the researcher can collect data from alternative sources of the same phenomenon or employ different data collection methods; if the data agree, he may have greater confidence in them, but this merely verifies their reliability rather than their validity. All data gathering instruments may possess a deadly flaw that prevents them from registering "truth".

The theme of this essay is not, however, data validity. The only reasonable attitude to assume is that if data are gathered from representative subjects with proper controls and adequate experimental design, these data should be considered valid unless or until proven otherwise.<sup>1</sup> The preceding discussion of validity was simply to suggest that if proving data validity is beyond us, we might well spend more time worrying about a problem which is more solvable. That problem--relevance--is one which is particularly important to HF, with its (HF) broad scope and goal of assisting system development.

The reason for being concerned about relevance is that data can be valid (at least to the extent that one can determine validity) and yet completely irrelevant.

Relevant to what? In HF, because its major goal is to assist system development, relevant to the questions posed by that development. In practice this means the questions asked by developers, since it is the answers to these questions that influence his decisions; it is these questions whose answers require data.

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<sup>1</sup>All behavior (e.g., human performance) is valid since it occurred (or at least it occurred according to our measurements); but what aspect of "truth" did it reveal? This is the question of relevance which is distinctly different from validity. (Of course it is possible for data to be relevant but invalid, but this situation should occur only if the investigator has made serious data collection errors.)

In any discipline many questions can be asked. At the individual level, one can for example, ask questions about the subject's physiological responses, his attitudes toward stimuli or his aptitude for or his performance of a task. At the system level, one can ask questions about his performance at a work station the system variables affecting that performance and the contribution of his performance to system output. Are all of these questions equally important?<sup>2</sup>

The answer to this is difficult in most disciplines but in HF in which system development plays such an important part, and in which a performance criterion--system output efficiency--exists, importance and relevance are largely determined by the factors influencing design decisions. In most disciplines the connection between data and the potential uses of those data may be fortuitous; much emphasis is placed on "basic" research because almost any answer may turn out to be important, hence the criterion of relevance applies much less to basic data.

The difficulty such disciplines have in pinpointing needed data has paradoxically been turned into a virtue; since most research cannot anticipate the usefulness of its data, it is a positive virtue to collect data (i.e., basic data), much of which may be relatively useless.

It may be objected that research is basic and important because it can lead to many different uses (applications) rather than merely one, the point may be made that research directed at a specified use leads only to the satisfaction of that use, whereas if it had been more general, it could have had several different uses. This is a matter of research strategy; research directed at a single potential application may be more economical of resources (even though it leads to only a single application) than is research whose multiple applications are unspecified and much of which miss their aim.

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<sup>2</sup>In this discussion relevance and importance are equated. All questions are not equally important, at least in HF. The criterion of its criticality to system output determines the relative importance of a variable. If a variable is hypothesized to have relatively little effect on system output, then a question centering on this variable is also relatively unimportant. Is research to answer the question, what is the most desirable color for consoles, as important as the question, what is the most appropriate means for deriving personnel requirements from an equipment configuration? This is not to say that the former question is absolutely unimportant, but that it is less important than the latter. And of course the judgment of relative importance is idiosyncratic and may be incorrect. The point is that an efficient research strategy requires the researcher to make choices about what he will study, since he cannot study everything.

The point is that HF data may or may not be relevant to system development questions. Each set of data has a potential use and these uses vary. For example, data on detection probability as a function of target size will not answer training questions; and training data will not serve to determine whether target size is sufficient for detection. Those who insist on the sanctity of basic research and the criterion of researcher curiosity will provide data that may or may not answer system development questions. If the data do not answer these questions, they will remain unused by developers--regardless of their validity.<sup>3</sup>

In the preceding example both training and detection data will be useful to some system developer (although most likely not the same ones) and therefore there is no loss even though not everyone can use all data. Data that do not answer any system development questions are of course largely useless, but hopefully there are few such data.

The point to be emphasized is that in the collection of HF data it is necessary before beginning data collection to specify the questions the data will answer. Of course, if one assumes that any data one collects will be useful to someone, then the preceding prescription need not be taken.

HF data that do not answer system development questions (again considering system development in its broadest sense) have dubious value, since the primary goal of the discipline is to assist in system development by learning how systems function. Unfortunately too much behavioral data are gathered that fail to satisfy that goal. The proof of the pudding is that there are a vast number of questions in system development for which we have no answers (see essay 17 for a list of the most important research topics).

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<sup>3</sup>In the HF discipline, who else will use these data? Other HF specialists? who build upon them an ever higher tower of research--which in turn leads to further research.

It is probable that before beginning his study the researcher has in the back of his mind some use to which his data could be put. However, this use is often quite vague. Moreover, it is unlikely that the majority of researchers conceptualize that use in terms of the system development goal. In a discipline which has many questions to answer and whose resources are highly limited, it seems wasteful to allow research to proceed in an unsystematic manner. This is a matter of research management rather than of a specialist technique and it is particularly appropriate to talk about management in a discipline whose research is largely supported and directed by governmental management agencies. If one can specify data needs arising from system development and operational problems, is it not logical to direct research toward the solution of these problems? Of course, the questions posed must not be trivial.

One might also consider that it is possible for research directed at system development and operational problems to suggest hypotheses dealing with more general (basic) considerations; in fact, a strategy of having system development and operational research results suggest more fundamental research questions may be more meaningful than the more traditional method which is the reverse.

The first step in the HF research process is therefore to determine what needs to be known. This means finding out what the system developer thinks he needs to know (or what the HF specialist thinks the developer should know). As was pointed out in a previous essay, the HF researcher need not feel short changed by directing his efforts to topics suggested by system development and use, since the problems these present exceed our present human resources.

Some readers will object that this process will permit only applied research. Even if this objection were valid (and it is not), I would answer that as between applied research that is useful and basic research which is not, I would opt for that which was useful. It may be heretical to suggest that before a discipline such as HF can become "truly scientific", it must be useful. After all, mathematics began as an effort to assist Egyptian farmers to measure their farm lands.

I should not like to give the impression that I believe all behavioral data are useless. Data dealing with relatively molecular functions like detection and tracking are quite useful in optimizing the man-machine relationship. However, data dealing with more complex molar functions such as training and decision making have very restricted usefulness if one attempt to apply these to system development. Available relationships between equipment/system and behavioral variables are so gross and qualitative that the developer can make little use of them in tradeoff decisions.

Some may think of HF as an aesthetic discipline (the art form referred to in essay 4) but I do not. Nevertheless, data that do not satisfy a need and that do not solve a problem can be considered at best as an aesthetic product, like a painting or a poem. The first task of any discipline, particularly one that is relatively young, is to be useful. Usefulness means relevance. Relevance means finding out what questions need to be answered. In HF the purpose for which the system is being developed gives us a clue concerning the information that development needs. It is the researcher's responsibility to follow that clue.

## 15. ON THE INDETERMINATE MAN-MACHINE SYSTEM<sup>1</sup>

If one wishes to generalize HF data from one system to another, it is necessary to develop a system taxonomy, i.e., a scheme for classifying systems in terms of their similarities and differences.

One may ask of course why one should be concerned about taxonomizing systems as distinct from taxonomizing task behaviors, many attempts at which have been made, e.g., Berliner et al., 1964. Tasks describe the operator. If it assumed that the system is more than the operator, the former cannot be described in exclusively task terms, although there is obviously considerable isomorphism between the system and its tasks. Much of the difficulty of applying behavioral principles to the development of these systems may result from the type of system in which these behaviors are embedded. In other words, variable X may be more important in one type of system and less in another. One cannot therefore understand the effect of an operator's performance on system output without understanding the type of system in which that performance occurs. This in turn demands a taxonomy of systems as well as of tasks.

Many variables influence MMS performance: The number and type of subsystems; the variability of operating procedures; the nature of system requirements; the characteristics of required tasks; the number and background of personnel, including their training and experience; the system's communication structure, the number, frequency and characteristics of inputs and outputs, performance criteria (those describing the system, the mission, and the operator), and various environmental factors. (See Chapter 1 of Meister, 1976, for definitions of the preceding.)

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<sup>1</sup>A slightly different version of this paper was published in the Proceedings of the Human Factors Society, 19th Annual Meeting, October 14, 1975.

Each of these variables has several sub-variables, so that the number of factors affecting the system is very great. Is it then possible to find some taxonomic concept which unifies these variables?<sup>2</sup>

Systems differ most obviously (and therefore have traditionally been taxonomized) in terms of the functions they perform (e.g., command/control, surveillance, transportation, etc.), but these functional differences are not very useful in explaining operator behavior, because the same operator behaviors may be required in different systems. For example, monitoring discrete indicators is required in both ground-based command/control and flight tasks. Systems can, however, be differentiated in terms of dimensions other than those of functions.

One dimension cutting across the many variables influencing the system and subsuming at least some of them is the dimension of indeterminacy which Katz (1974) views as a phenomenon which is "a definite part of the structure of systems".

Indeterminacy can be roughly equated with uncertainty; the greater the uncertainty, the more indeterminate the system. Since it is natural to equate uncertainty with amount of information processed, it may eventually be possible to define indeterminacy in terms of the amount of information the system processes. Presently, however, it is possible to do so for only very simple functions.

One may however view indeterminacy in a simpler, although probably a less precise quantitative manner, in terms of the structure than can be imposed on the system by its developer. In Katz' formulations indeterminacy is related to the

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<sup>2</sup>In addition to a system taxonomy which is verbal, is it possible to think of describing the system in graphic terms? The elements of such a graphic descriptive methodology might include the following: Each work station would constitute a system node and would further be connected by various lines, each representing degrees of dependence among work stations. The work station node would be described by symbols representing required skill level, number and type of operators, frequency of equipment operation, types of inputs, probability of input occurrence and other variables described in the third paragraph. Assuming that it were functioning, one could plot these in graphic and numeric terms. Different systems could then be compared in terms of their graphed similarities and differences. What I am suggesting is in some way similar to the graphic analyses employed in motion and time study but far more complex. Since system functioning varies over time it might be necessary to have a series of such charts for major mission periods.



number of options the system has. An indeterminate system has great potential and actual variability in its operations.

In the context of the man-machine system I view indeterminacy as defined by:

1. Input characteristics: Inputs may vary in terms of their structure, variability, and patterning. For example, unprocessed radar/sonar imagery is highly unstructured, which makes it difficult to interpret. Inputs which change their characteristics frequently over time are variable; if their elements are closely related to each other, they are patterned.
2. Procedural variability: This is the extent to which operations can be varied during system functioning. If the system is so designed that its operating procedures require little or no operator selection among alternative responses, the system is highly determinate.
3. Response programming: The response required of the operator may or may not be specifiable in advance of the input which elicits the response. For example, if the sonar operator must classify his inputs (however they vary) as submarine or non-submarine, the system is response-programmed. If the operator is highly responsive to varying input characteristics, the response is less programmed.

All three of these factors are, although independent, of course interactive. When input variability is high, operator responses must be highly contingent to accommodate that variability. The procedures available to the system for making this accommodation will therefore also have to be flexible.

Despite this flexibility, the effects of indeterminacy on operator behavior are generally negative: reduction in the probability of performance of the correct response and increased probability of degraded response quality. One of the effects of indeterminacy is to impose a special type of load on the operator. Load conceptualized as an excessive number of inputs is not the critical problem in indeterminate systems, although one may find it there also. This kind of load is most important in determinate systems, and it can be dealt with by increasing operator productivity. However, informational uncertainty represents a different type of load which is more difficult to deal with because it butts up more quickly against operator limitations.

The ultimate factor requiring an indeterminate system may be a highly stochastic environment which makes it difficult to establish firm criteria for differentiating inputs and to predict the consequences of outputs; this in turn leads to inability to program responses. Operator control over highly stochastic environments presents problems. Environment is considered here very broadly. It encompasses geography external to the system (e.g., terrain) and any structures within that geography, an adversary system (i.e., an enemy), or the structure of one's own system (e.g., the physical hardware interface) which is the operator's environment. Because all inputs arise ultimately from the environment, indeterminacy is viewed as primarily an input problem, although it has consequences for response-programming.

There are of course different degrees of system indeterminacy:

1. Highly determined: Inputs are highly structured, invariant, and patterned, requiring little or no interpretation and easily predictable. Procedures can therefore be specified in advance of operation in step-by-step, go/no-go form, as can operator responses and system outputs. An example is the now obsolete Atlas missile launch subsystem, in which inputs were console indications (either red, amber, or green) with relatively unambiguous meaning. The operating procedure called for simple activation of a series of switches in a prescribed order; failure to perform a required step in the prescribed sequence prevented the launch from proceeding. Highly determined systems such as the Atlas are those in which there is little or no uncertainty about environmental inputs or the consequences of system operations.

2. Moderately determinate: Inputs are relatively unambiguous and invariant, the procedures to be employed, although predetermined in general outline, can be varied in specifics if the overall task situation changes; the nature of the operator response is clearly specified in advance, although again the manner in which it is performed may vary. An example is the air traffic control system.

3. Moderately indeterminate: The essential factor here is that inputs are variable, ambiguous, and require searching interpretation. Depending on that interpretation, the operator selects one of a number of alternative but pre-programmed procedures; the operator response is also one of number of responses

specified in advance. An example is an ASW sonar system in which the procedure followed depends on whether the inputs are classified "submarine" or "non-submarine".

4. Highly indeterminate: Inputs are ambiguous, rapidly changing and/or provide incomplete data. The procedure to be followed depends completely on interpretation of momentary input characteristics and cannot be specified, except generally, in advance of operations; the procedure is highly contingent on event occurrence. An example is a tactical system, e.g., division headquarters during an attack, where inputs are fragmentary, the order of battle must be progressively built up and the successful response (which will counter the enemy) is a probability only. Such systems contain much uncertainty.

One of the major themes running through highly indeterminate systems is that the consequences of actions to be taken by him are difficult for system personnel to anticipate. In the battle situation action X on the part of own system may or may not be successful and may evoke response Y, which was not anticipated. The most indeterminate systems involve a high order of decision making on the part of their operators. Feedback may be delayed and highly probabilistic. Obviously, only the extremes of these system situations can be clearly differentiated. Most systems are neither wholly determinate or indeterminate, but contain elements of both. For example, in helicopter flight at nap-of-the-earth, the navigation function which depends on very detailed analysis of microcues in the terrain is highly indeterminate, but the aircraft control function is much less so. In this connection indeterminacy need not involve purely cognitive functions. Some psychomotor functions (e.g., tracking) in certain systems may also be highly indeterminate.

Since indeterminate systems are likely to be less efficient than one would wish (because of the contingency factors involved), the goal of the HF specialist in system design is to eliminate as many sources of indeterminacy as possible (to develop what Katz calls "bounded indeterminacy"). Theoretically, complete indeterminacy would lead the system to complete collapse. From that standpoint, the more rigidly programmed a system is, the better from a system output standpoint--within limits. Of course a minimal amount of procedural flexibility is desirable to reduce operator boredom. Katz (1974) points out that "the limits of imprecision that a system can tolerate are related to the character of the total system". This suggests again the desirability of determining the characteristics of various types of systems.

Indeterminate systems are obviously of special interest to the HF specialist because processes in these systems are highly dependent on the operator and can be affected by self-regulatory processes. Motivational factors are particularly critical in such systems. Another reason for being concerned about indeterminate systems is that there is only limited need and opportunity for HF services to improve highly determinate systems which are comparatively simple to develop. Unfortunately, many HF methods (particularly human engineering principles) are not very suitable for solving indeterminate problems. Although these methods can be applied to indeterminate systems to solve their human engineering problems, they cannot help very much to reduce indeterminacy. To reduce indeterminacy, principles dealing with information processing, decision making, feedback, task organization, etc. must be applied.

Although behavioral principles are important, therefore, for system development, these have not unfortunately been studied in a system (i.e., input-output transformation) context. Consequently the task of applying these principles to reduce indeterminacy is very difficult. For example, one might suppose that the addition of feedback would help to reduce indeterminacy by providing knowledge of action consequences; but in real world situations it is often difficult to determine feedback veridicality. One might also attempt to increase the number of sources of environmental information reaching the operator, so he can assess the reliability (consistency) of his inputs; but this often runs up against cost and feasibility factors. Most HF principles help to explain how indeterminate systems function, but do not indicate how such systems can be more effectively developed or modified.

Fortunately the operator is adaptable and displays this characteristic most obviously in indeterminate systems. There may be an inherent tendency for the operator (and the system as a whole) to seek a more programmed structure.

It is possible that as the MMS continues to function in the operational situation it becomes progressively more determinate through what can be called "system learning", i.e., the determination by operators of which contingencies are most likely to occur and which responses are most likely to be successful.

One possible way of measuring the indeterminacy of complex systems is to ask operators at any specified time to predict the probability of the next stimulus/ input to appear and the next response they will have to make. The lower the probabilities estimated, the more indeterminate the system.

It is also fascinating to consider how the variables affecting system performance which were listed at the start of this essay might change their values as a function of the indeterminacy dimension. For example, it is possible that in more indeterminate systems the arrangement of communication channels is likely to be more flexible to accommodate the additional options open in such systems. Indeterminacy thus may supply a new conceptual orientation with which to study familiar variables in the system context.

## 16. ON CRITERIA FOR EVALUATING HUMAN FACTORS RESEARCH

A theme repeated a number of times in these essays is that the overriding goal of HF is to assist in the development of the MMS. This has a direct relationship to whatever criteria of "adequacy" one applies to HF research.

Traditional scientific concepts emphasize the experimental method and what might be termed "internal" criteria because they are inherent in the characteristics of the research itself. These include, among other factors, the representativeness of the subjects, the size of the subject sample, the experimental controls imposed and an appropriate statistical design. Such criteria are necessary even under the somewhat specialized conditions of HF data collection in which the experimental method may be difficult to apply.<sup>1</sup>

Nonetheless, whereas other behavioral disciplines may find internal criteria sufficient, HF demands more of the research it considers "adequate". Because of its goal of assisting MMS development, an additional criterion of satisfactory HF research is the extent to which that research can be applied to design/development. By this standard, a study can meet all the internal criteria of effective research and still be trivial because it is irrelevant or cannot be applied to system development (in its broader aspects, of course). This is because not all behavioral research results can be automatically translated into system development guidelines and data; only relevant research can be so translated.

There are two possible objections to these propositions. The first is that it is difficult to specify the developmental relevance of a study before the study is performed. The second is that by concentrating on relevance to a narrowly defined problem area the resulting data are limited to that problem alone.

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<sup>1</sup>A factor that may make internal research criteria insufficient for HF is that one of the conditions for applying such criteria may not exist. I refer here to the necessity for controlling the situation experimentally (most often in a laboratory). In another essay (11) I have explored the difficulty of performing traditional experimental research with large MMS which cannot be moved into the laboratory or adequately controlled in the operational setting. Should research that must be conducted under such conditions be considered "inadequate"?

I submit that it is not difficult to determine in advance whether a given piece of research will be more or less applicable to system development. All one needs to do is to hypothesize the relationships one anticipates finding and to imagine translating these results into a design "prescription". If one cannot conceive of research results being translated into a concrete<sup>2</sup> principle of system development, the research is non-applicable.<sup>3</sup>

By this design-application (external) criterion a very great amount of behavioral research fails to be useful for HF purpose. In most cases these studies satisfy the internal criterion (at least minimally) but fail the external one.

The second objection to the concept of the external criterion is related to the distinction between "basic" and "applied" research. As I interpret it, the term "basic" implies getting down to some root-source or origin, as being fundamental, as leading to other relationships. This suggests that basic research can be utilized to explain a number of derivative relationships. I define applied research as being problem-oriented, i.e., responsive to or solving a problem.

Both terms have stereotyped connotations which are not necessarily correct. The stereotypical connotation of basic research is that it explores a theory. The stereotypical connotation of applied research is that it is narrowly limited.

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<sup>2</sup>"Motherhood" (excessively general) statements do not qualify. See essay 18 for a definition of the design prescriptions needed to make behavioral data useful for system development.

<sup>3</sup>Can such research be useful for other purposes? It may help to further one's general understanding but I suspect that unless it can be applied more or less directly to development the amount of additional understanding it fosters is minimal. There is, after all, a point at which generalities must give way to specifics.

In HF much fundamental research has no clear link with theory.<sup>4</sup> For example, nothing is more fundamental (basic) to problems of predicting and measuring human performance in the system context than the availability of a storehouse of data on operator performance in relation to various parameters. (See the following essay for a description of HF research needs.) And yet this research problem has no link with a specific theory. Indeed, research directed at building up such a data bank would probably miss the accomplishment of its goal if it concentrated on a particular theory.

Problem oriented research need not be limited at all. If the problem is sufficiently important--and it should be possible to differentiate between trivial and important problems--then at the core of the problem the researcher will find variables which function in many contexts. For example in studying the problem of navigating a helicopter at "nap of the earth" (Fineberg 1974), the operative variables (visual perception in map reading, perceptual/decision making; communication) are to be found in many systems.

From that standpoint, if the problem selected is important enough, problem-oriented or what most specialists would call applied research need not be highly limited. Actually the problem orientation prevents the researcher from working on trivial variables because a genuine problem must have at its core fundamental factors. Indeed, it is possible that basic research variables can be meaningfully examined only in the context of real world problems, since a basic variable that has no impact upon operational reality cannot by definition be basic.<sup>5</sup>

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<sup>4</sup>If HF is defined as the science of man-machine development and functioning, then the discipline has very little theory at least as it relates to systems. There are however a number of individual-oriented psychological theories of target acquisition (see Jones et al., 1974), theories of vigilance (see McGrath et. al., 1959), etc. It is possible that such individual-oriented theories and the basic research performed in support of them are not appropriate at the system level. In other words, what we presently consider basic research may be suitable at the individual level, but new types of research and certainly different problems are suitable at the higher level.

<sup>5</sup>This does not mean that research on real world problems must be performed in an operational environment. Depending on circumstances, it may be more convenient to perform it in a laboratory setting.



The reason for being concerned about the distinction between basic and applied research in HF is because of the opposed pressures imposed on the researcher. As was pointed out in essay 9, the government directly or indirectly is the primary sponsor of this research. On the one hand, the government's interest is highly problem-oriented. On the other hand, many researchers have been indoctrinated by their psychological training to feel that the only adequate research is that which can be termed "basic" or theoretical. The pull and tug between these opposing forces not only creates much confusion but degrades the quality of the research.<sup>6</sup>

Because of its subject matter and goals, HF research must be inherently problem-oriented. This may lead the research purist to look down on what we do, but as long as the discipline maintains that problem orientation it can probably survive their disapproval.

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<sup>6</sup>I should not like to give the impression that it is possible in any specific case to point to the research and say unequivocally that this is basic or that applied. This is part of the problem, because in the absence of objective indices of what is basic or applied, attitudes substitute emotion for logic.

## 17. ON HUMAN FACTORS RESEARCH NEEDS

In essay 14 it was suggested that possibly not all research topics are equally important and that the overriding significance to HF of the MMS and system development establishes a priority of research topics. What are these most important topics?

Research interests are mostly idiosyncratic but the logic of the concepts expressed in this volume suggest that the greatest need is for a storehouse of probabilistic data predicting the likelihood of personnel success in accomplishing a variety of system tasks under various conditions. The immediate application of such data to system development is obvious. To compare two control panel design alternatives meaningfully, for example, the HF practitioner must know the probability with which a well trained operator will correctly operate a panel containing different numbers and arrangements of controls and displays. This probability value should be expressed to at least two decimal places and should represent the proportion of times out of 100 or 1000 operations that the panel would be correctly operated. Expressed in tabular form the data (if it existed) would look something like Table 1.

Table 1. PROBABILITY OF CORRECT CONTROL PANEL OPERATION<sup>1</sup>

<u>Number of Controls</u>	<u>Number of Displays</u>	<u>Probability</u>
1	1	.999
1	2	.999
2	2	.998
2	3	.996
etc.	etc.	etc.
or		

<sup>1</sup>Or whatever level of behavioral/task description one desired. There would of course be tables for other tasks and conditions.

Number of controls/displays

Probability

Between 1-5

.990

Between 6-10

.885 etc.

Data should be available for a great variety of tasks ranging from the very molecular (e.g., turning a valve handle) to the very molar (e.g., integrating intelligence inputs), performed under non-stress and stress conditions, with and without environmental constraints, etc. Data should also describe maintenance and team performance; when reasonably comprehensive it would fill a thick book. The tables developed by Munger et al., 1962, are representative but very molecular. Naturally Table 1 represents an ideal, not to be accomplished immediately, perhaps not for a short time, and certainly requiring strenuous efforts.

A data base such as the one illustrated is essential to the system developer who must choose between alternative equipment configurations (one of the criteria for such a choice being the operator performance one would expect from each configuration). At the present time comparative evaluations are made subjectively and unsystematically (see essay 4 for comments on this point).

The effort to develop such data tables has been pursued since 1962 under the rubric of "Human Reliability" (see Swain (1969) for a resume of the efforts made in this direction). Since the purpose of this essay is not to describe Human Reliability as such, no extensive description will be given of this movement, which in any event has not achieved popularity among HF specialist.<sup>2</sup>

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<sup>2</sup>I have wondered for many years why this effort was not picked up and pushed by HF specialists generally--since Human Reliability in a simplistic sense can be viewed merely as the formalization in tabular form of traditional performance measurement data--but it has not. It may have been the "yellow stain" it received by its close association with engineering reliability; it may smack too obviously of application; the fact that the goal of the effort is simply data gathering and not hypothesis-testing may have damned it. In any event we have practically no such predictive data (except for Munger et al., 1962, which is primitive at best) and so the HF practitioner is short changed.

Two points before passing on to the next most important research area.

(1) The necessity for a data base (in the sense of tables of quantitative data) rests on the fact that one cannot successfully develop MMS (from a behavioral standpoint) with general principles. Moreover, if, as suggested in essay 13, general behavioral principles can be derived phenomenologically, then the behavioral research emphasis should be placed not on hypothesis-testing, but on the assembly of data bases.

(2) The data base collection effort may require an observational rather than an experimental approach. For one thing, the number of experiments needed to provide the requisite data is prohibitive. For another, behavioral scientists have generally overlooked the fact that they have in the real world a tremendous pool of subjects performing a great variety of real world tasks whose performance has never been systematically measured. Because one cannot interfere with what these personnel are doing, data collection would have to utilize some variation of observation.

Next in priority is the need to develop methods that will permit the developer/practitioner to derive the human performance, manning, selection and training implications to be drawn from equipment configurations and procedures. In other words, if I (the developer) have a design which has the following characteristics, what can I deduce as behavioral requirements from that design? The behavioral implications of equipment and procedures are the essence of HF and represent the qualitative aspect of the data base effort.

The need for such relationships is practical (what could be more practical than examining a design drawing and saying to the engineer, if you use this design you will need an operator with skill level E-7 whose training will require 10 weeks and you can expect him to operate with a success rate of approximately .86?<sup>3</sup>). At the same time we are dealing here with fundamental relationships (as fundamental was defined in essay 16) because they are at the heart of the HF discipline.

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<sup>3</sup>Again the illustration represents the ideal deduction to be made from the drawing. It may not be immediately possible to be so specific in one's conclusions.

Another research area at the same level of priority as the preceding is actually its reverse. The research need here is to develop techniques which will permit the HF practitioner to draw equipment implications from personnel data. Specifically, what equipment and procedural implications can be drawn from data on personnel aptitude and availability, skill and training requirements, etc? For example, if the system developer is handed the requirement that for system X only low level (e.g., 3-skill) personnel are to be utilized, how does this requirement translate into design guidelines? Beyond of course the superficialities represented by the injunction "make the equipment simple." The need for translation techniques is a very practical one since such requirements are imposed frequently; but developers (and that includes HF specialists) do not know what to do with them. This research need, like the preceding one, is fundamental to HF because it reflects the essence of the man-machine relationship.

As a third order research priority (although related to the previous topics) it is necessary to know a great deal more about three things: (1) how system development proceeds in detail and how HF inputs to that development are ordinarily requested, received and utilized; (2) what developers need to know (from a behavioral standpoint) in order to do their jobs; and (3) how systems adapt their behavioral functions over time to operational demands.

For all the importance of system development there have been few if any studies of the processes involved, at least in terms of behavioral parameters. If HF is to accomplish its goal of assisting in that development, it is necessary for specialists to know much more about these processes. Similarly since assistance in development requires the practitioner to provide inputs to the designer and to help him use these inputs, it seems reasonable that one should determine the information the latter needs and wants. One or two studies focussing on the problem have been performed (e.g., Meister et al, 1968, 1969) but hardly enough to answer the question. We know even less about how systems function behaviorally after they have been developed, whether the behavioral functions designed into the system perform as they were intended to and if not, why not and how they were changed.

All the research topics above, it should be emphasized, are research areas, requiring a number of studies. This is particularly true of the development of predictive data bases; these will require many studies and continuing research for the indefinite future. It is unlikely that problems of this magnitude will be solved by a single study, however comprehensive.

Establishing a set of priorities implies that the research given lower priority is of less value, but it would be invidious to attempt to specify these non-preferred research topics. The listing in this essay is not merely a matter of personal preference; if this were so, anyone's research would be as valuable as anyone else's. The topics suggested are dictated by the problem context in which HF functions.

## 18. ON THE IMPORTANCE OF HANDBOOKS

If it is important for HF to assist system development by providing data and behavioral design guidelines to developers, then the handbook is of crucial importance, because this is the one method with which one can assemble, summarize and organize masses of information.<sup>1</sup> It is also in line with the activist orientation of HF that data gained through research should be codified and put to use rather than allowed to gather dust in scholarly journals and reports. I am more than half-serious when I suggest that effective HF research is that research the results of which can find their way profitably into a handbook.

Past experience indicates, however, that it is not easy to develop truly useful handbooks. Meister and Farr (1967) have shown that engineers reject most HF handbooks by failing to use them. Superficially this rejection results from the excessive verbiage found in most such handbooks and their failure to employ graphic materials; but the problem is much deeper.

The most serious difficulty one faces in developing HF handbooks is the lack of substantive data on practically every relevant topic, but this problem is general to HF, is not insuperable and has been dealt with in detail in other essays. Apart from this, the first requirement in developing a handbook is to decide on its intended audience. It is logical to assume that information will not be accepted by an audience unless that information is recognized as pertinent.

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<sup>1</sup>From the engineer's standpoint it may not however be the most desirable method of imparting information to him, since he often prefers to receive that information through direct personal contact.

The HF handbook audience as a whole is the system developer, but within that broad category it is necessary to pinpoint specialties who have needs for specific data. Within the development audience two types have been readily identified: the drawing board designer (who works at the detail level) and the system engineer (who works at the concept level), but within the category of designers we have been unable to differentiate them further (which is another reason for more detailed studies of system development and developers). There are moreover governmental system planners and personnel, training and cost specialists who probably have specific data needs that have not yet been clearly identified. The point is that it is perfectly possible to provide a great deal of valuable information to someone who has absolutely no need for it.

If the first requirement is to identify the particular system development specialty to which data should be presented, the next, which should be satisfied concurrently with the first, is to ascertain the particular problems or parameters for which this specialty needs data. This specifies the kind of data to be provided. It is impossible to describe the data needed for a particular handbook without first imagining the kinds of problems to which it will be applied. The bench level designer wants to know--or at least he should know<sup>2</sup>--the relationship between operator performance and control-display variables. The system engineer wants to know--or should know--how to trade off selection, manning, training and human performance factors against cost, system performance requirements, etc. Neither would care for the other's data because it would be irrelevant to his problems.

The handbook developer should therefore not simply include in one handbook all his available data, because much of these data may be irrelevant to the needs of his audience.

To be selective in his data gathering and presentation may be somewhat hard for the handbook compiler, because he has a natural tendency to wish to make available to the reader as much data as possible.

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<sup>2</sup>He may not be aware that he should know this.



Having once decided upon the data to be included in the handbook, it is further necessary to provide these in the form of design prescriptions. A design prescription is defined by the following paradigm: two or more variables are related to equipment thus and so. They influence the operator's performance as follows (here the data are described). These variables can be included in design in the following manner. Most important, to optimize the operator's performance the designer should, if at all possible, develop the following design configurations.

Such design prescriptions must be quite specific. Since the developer is almost always behaviorally naive, he needs guidance (the design prescription) in applying the data given him. Most HF handbooks have foundered in the past because they have simply provided data and assumed the user had the background necessary to apply it.

The development of design prescriptions is not an easy thing for the handbook compiler. It requires techniques (described in part in essay 17) that have not been formalized or may not exist. Ideally the handbook compiler should be familiar with design but if not perhaps he should collaborate with a designer who can at least review draft material. If the compiler accepts criticism honestly, he may have to discard much of his material as not having developmental utility or find an innovative way of relating that material to design. Including useless with useful material merely wraps the latter round with the former, making it difficult for the developer to differentiate the two.

If handbook material has been phrased as design prescriptions, the often mentioned problem of "translating" behavioral data into engineering equivalents disappears. I cannot believe that the engineer speaks a different language from the rest of us or that he cannot understand numbers and plain English when it is phrased in design prescriptive terms.

Above all, the handbook compiler must avoid excessive generality, and the use of such "motherhood" statements as "make design simple enough so that equipment can be operated by personnel of varying skill levels." Such a statement is not a design prescription because it cannot be acted upon by the engineer. What is he to do to make design simple? The operations necessary to guide his design are lacking. Consequently the statement is meaningless.

One can of course view the previous statement about simplicity as a criterion of correct design, even if it is not a design prescription. Human engineering specifications, e.g., MIL STD 1472B (1974) describe criteria, not design prescriptions, but engineers and HF practitioners alike try to use them for design guidance with indifferent success. It may be too much to ask that each human engineering criterion should be backed up by a design prescription.

We have also learned that engineers prefer to receive their data in the form of tables and graphs rather than verbally (Meister and Farr, 1967). This is logical of course: quantitative data are expressed most meaningfully in tables and graphs. Engineers may reject verbal statements because these do not include enough design guidance.

One cannot of course put data into tabular/graphic form unless the data fit that format. If behavioral scientists have had difficulty in the past meeting this requirement, it is probably because their data have not been insufficiently quantitative. Given that the handbook compiler has appropriate data, he will have no difficulty putting it into tabular/graphic form.

The decision to make the system developer the primary audience for HF handbooks has certain implications. It means that HF specialists accept the designer's informational needs as primary requirements. This in turn means that we make his acceptance of those data the criterion of handbook adequacy. In part we accept this proposition because the designer has major authority over the behavioral inputs given him: he can accept, reject or modify them within his broad responsibility for design. Does the designer have the necessary background to make such decisions correctly? No one knows, because we know too little about the tradeoffs made by engineers during design. This is another reason for exploring system development processes in more detail.

The fact that HF handbooks cater to system developers does not mean that we need ignore the HF practitioner. However, his material should be distinct from the engineer's handbook, although containing all the latter's data. The practitioner's handbook will contain material we may not wish to provide the developer, because the latter cannot assimilate it.

With regard to the acceptance of HF handbooks by developers, experience indicates that they are reluctant to use them, no matter how relevant the data included. That is because the engineer is typically highly conservative and reluctant to find new ways of doing his job. Considerable indoctrination and patience may be required. Given, however, handbooks containing useful data, it is an article of faith that he will eventually accept (i.e., use) them in his designs.

However difficult the problem of developing adequate handbooks, it is necessary to try to compile them. It is unacceptable that HF research should fail to reach those who need its results. Not only does this do a disservice to those who support HF research with public funds, but it also cheats the primary users of HF services.

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